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(12) **United States Patent**  
**Morgan et al.**

(10) **Patent No.:** **US 8,075,079 B2**  
(45) **Date of Patent:** **\*Dec. 13, 2011**

(54) **INK CARTRIDGE WITH BUBBLE POINT PRESSURE REGULATOR DEFINED IN LAMINATED WALL**

(58) **Field of Classification Search** ..... 347/6, 17, 347/86  
See application file for complete search history.

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*Primary Examiner* — Matthew Luu

*Assistant Examiner* — Janelle M Lebron

(57) **ABSTRACT**

An ink cartridge for an inkjet printer having a laminated wall. The laminated wall defines: an air inlet; a regulator channel having a first end communicating with the air inlet and a second end defining a bubble outlet; and a wetting system for maintaining liquid in the regulator channel so as to ensure that air entering a headspace of the cartridge first passes through said liquid. The regulator channel is dimensioned to control a Laplace pressure of air bubbles drawn from the bubble outlet as result of supplying ink to a printhead, and thereby regulates a hydrostatic pressure of the ink.

**9 Claims, 16 Drawing Sheets**

(73) Assignee: **Silverbrook Research Pty Ltd**, Balmain, New South Wales (AU)

(\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **13/046,768**

(22) Filed: **Mar. 13, 2011**

(65) **Prior Publication Data**

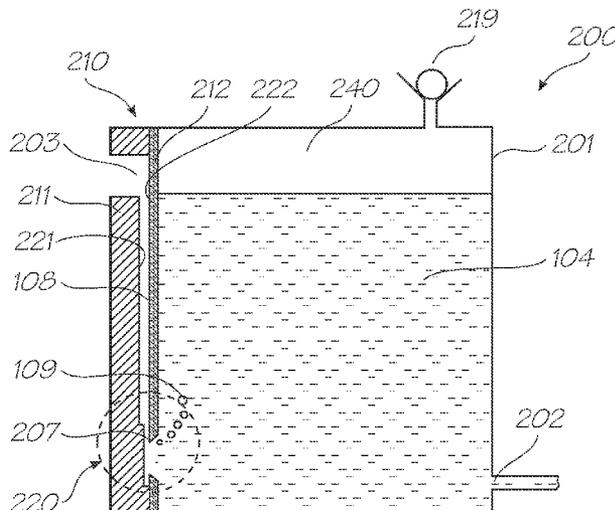
US 2011/0164099 A1 Jul. 7, 2011

**Related U.S. Application Data**

(63) Continuation of application No. 12/859,193, filed on Aug. 18, 2010, now Pat. No. 7,926,899, which is a continuation of application No. 11/679,786, filed on Feb. 27, 2007, now Pat. No. 7,794,038, which is a continuation-in-part of application No. 11/640,360, filed on Dec. 18, 2006, now Pat. No. 7,784,925.

(51) **Int. Cl.**  
**B41J 29/38** (2006.01)  
**B41J 2/175** (2006.01)

(52) **U.S. Cl.** ..... **347/17; 347/6; 347/86**



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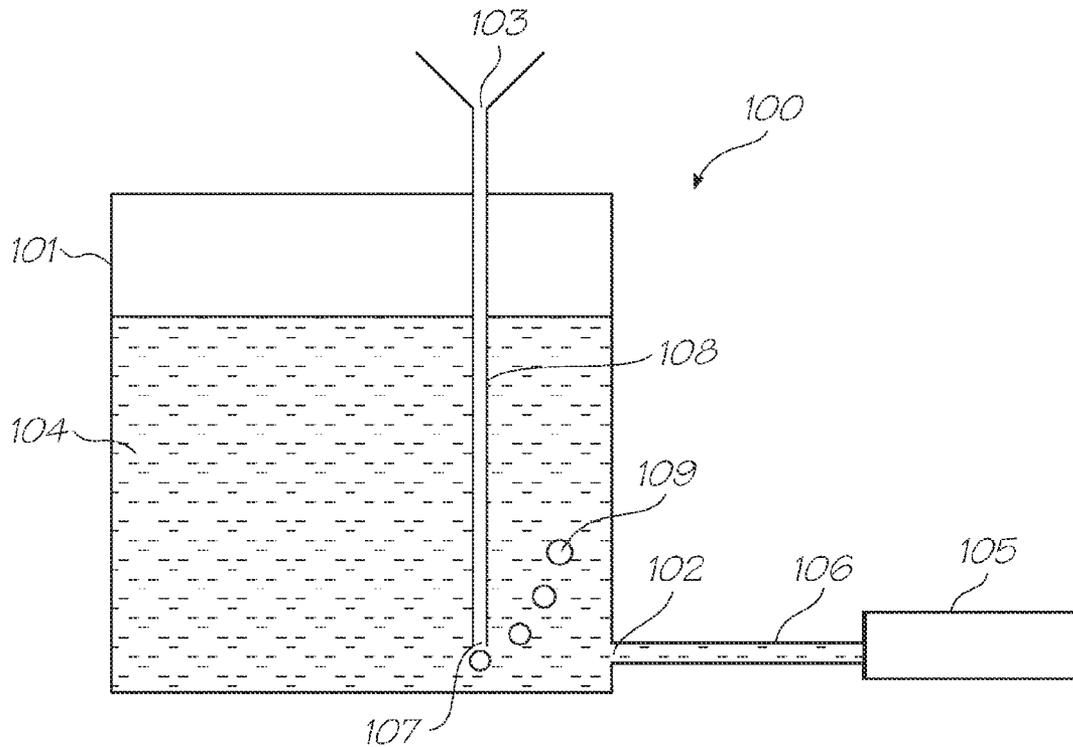


FIG. 1

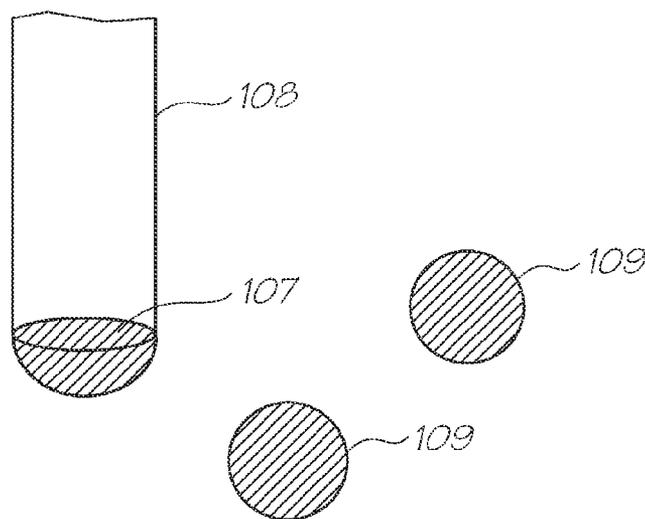


FIG. 2

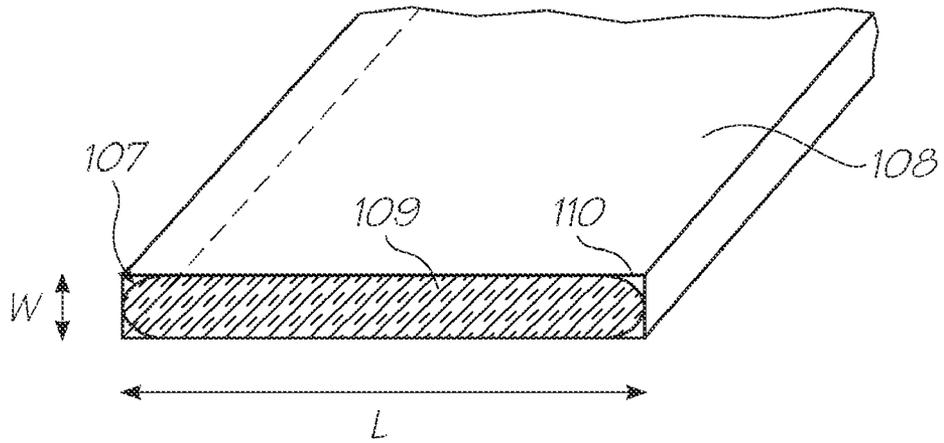


FIG. 3A

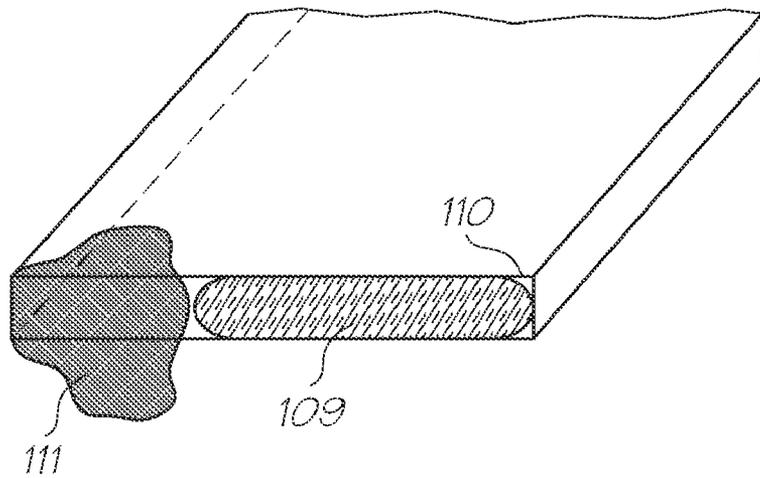


FIG. 3B

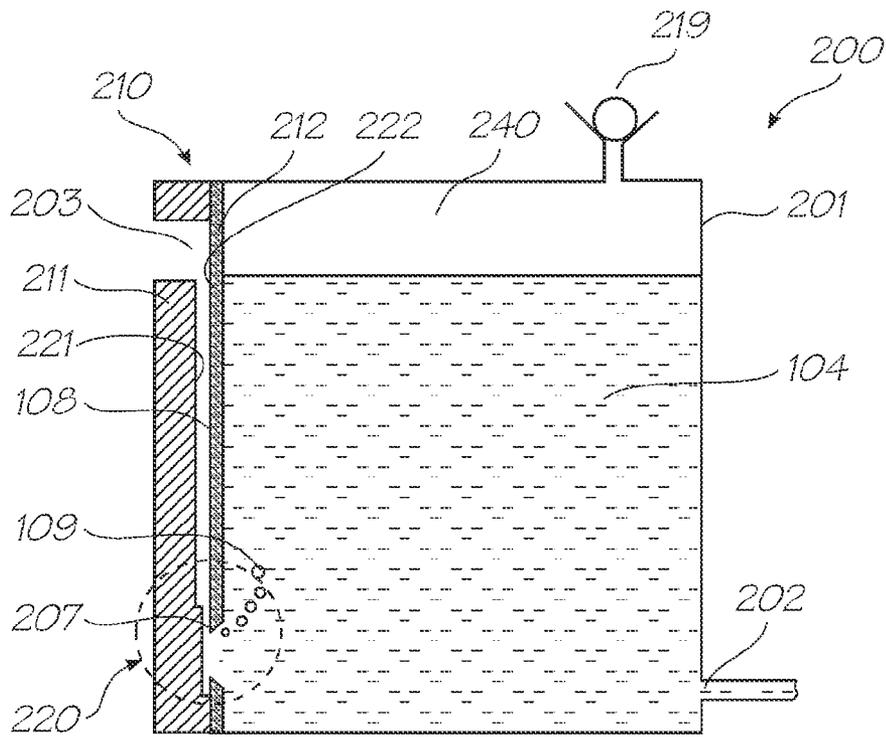


FIG. 4

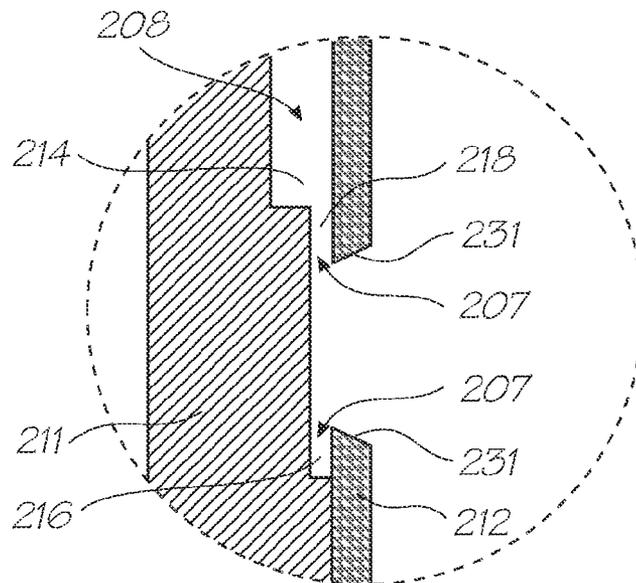


FIG. 5

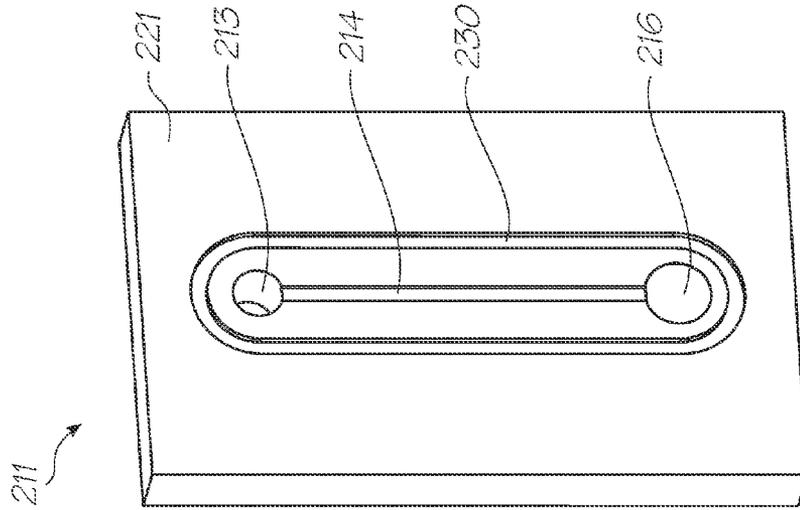


FIG. 7

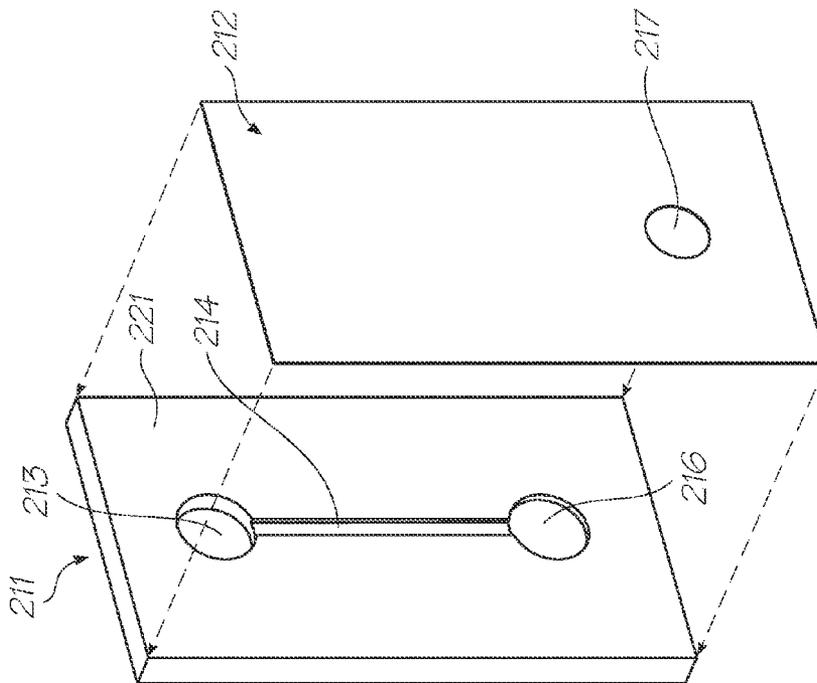


FIG. 6

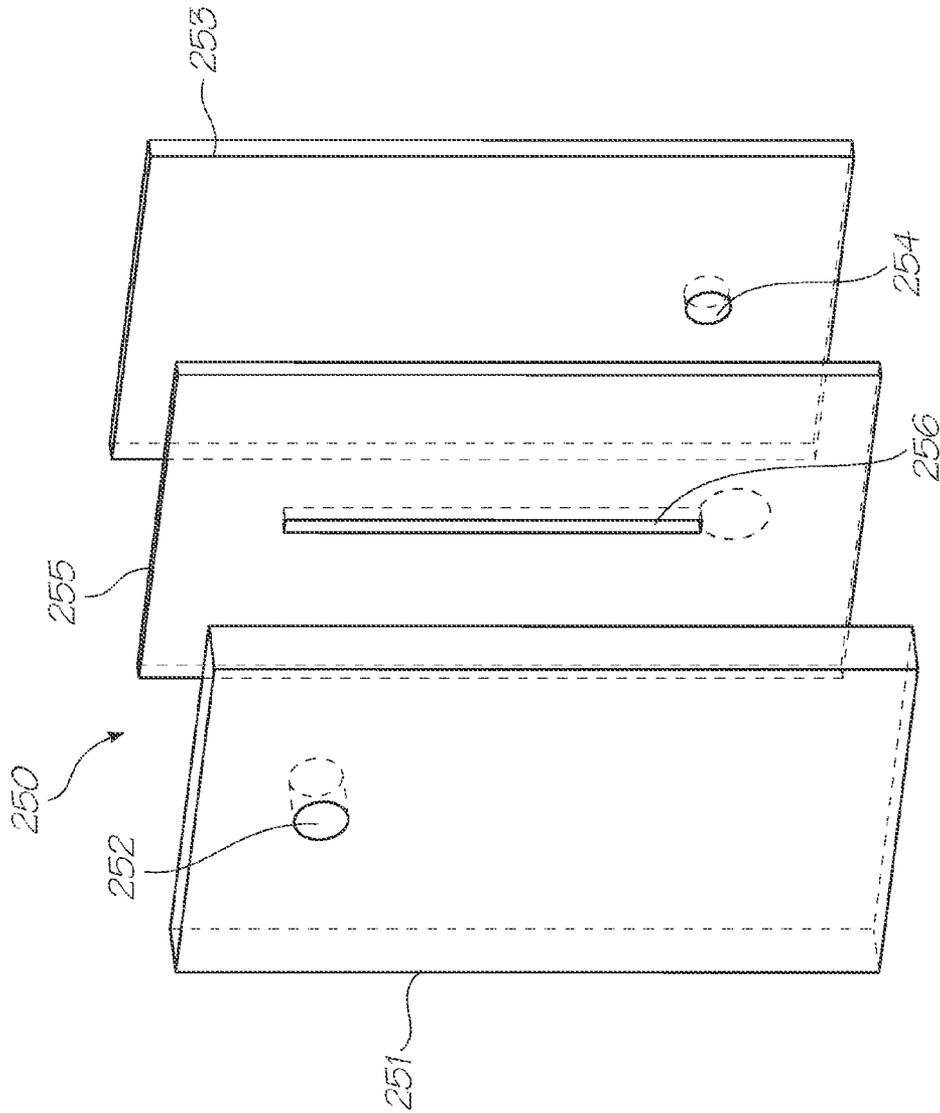


FIG. 8

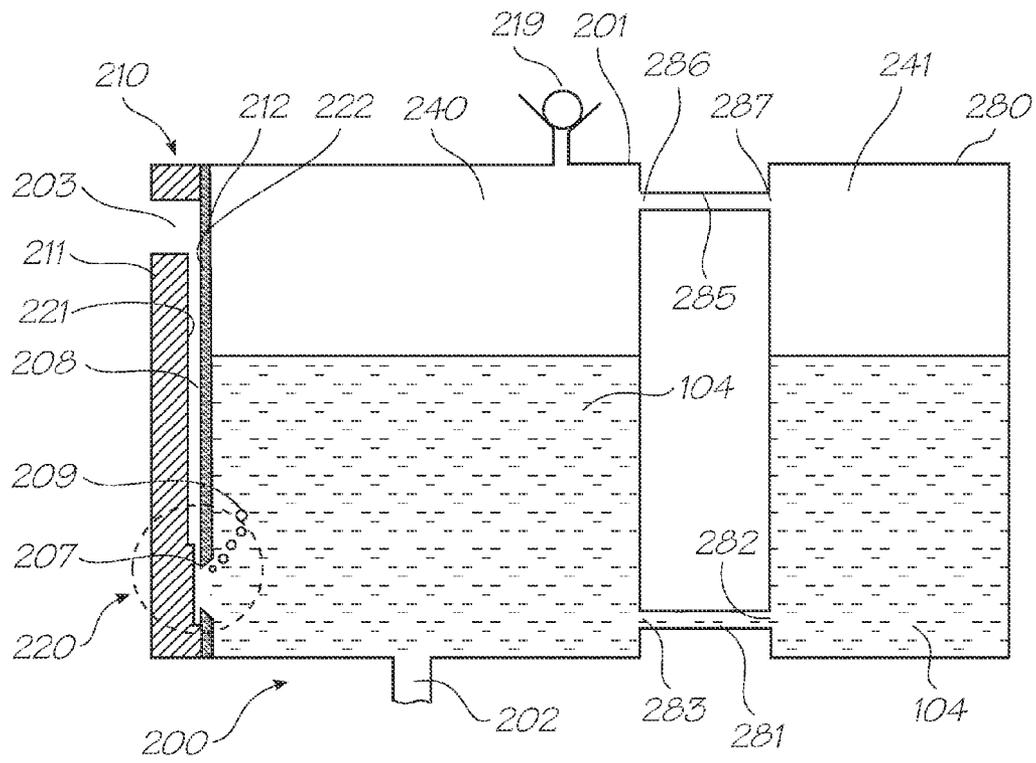


FIG. 9

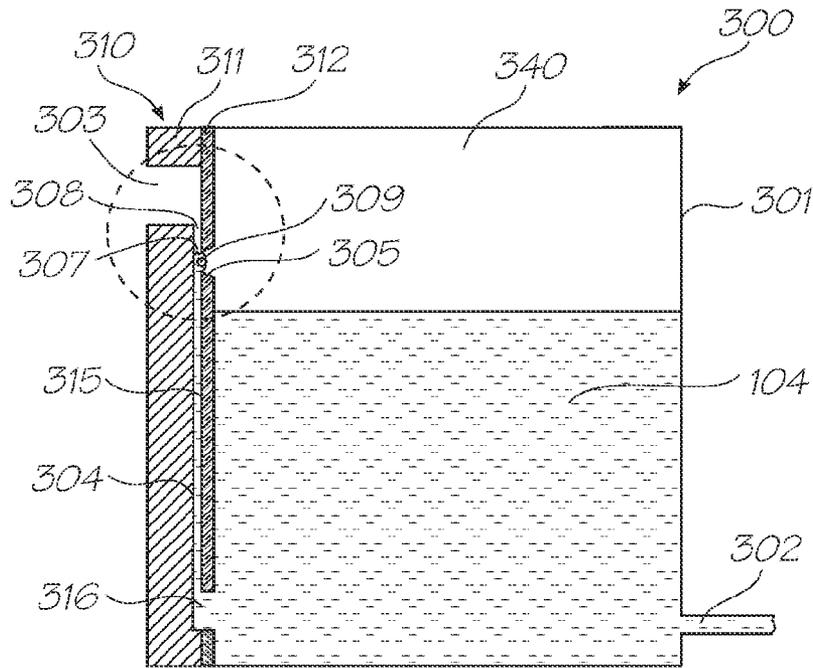


FIG. 10

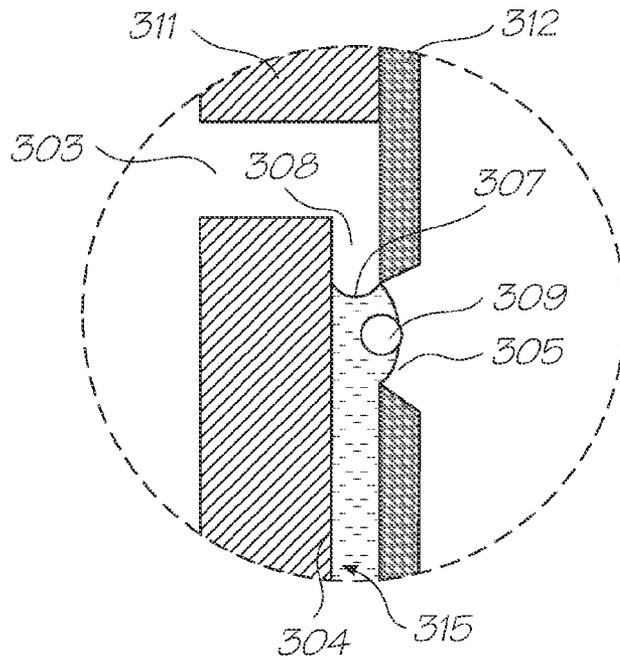


FIG. 11

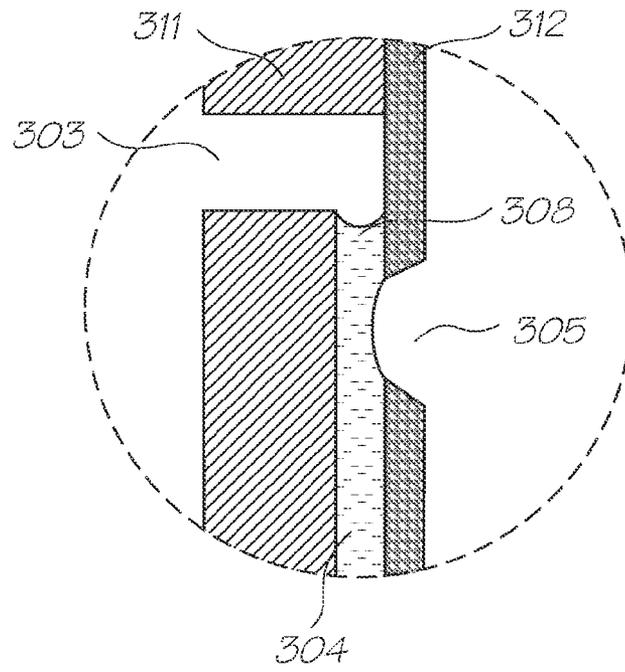


FIG. 12

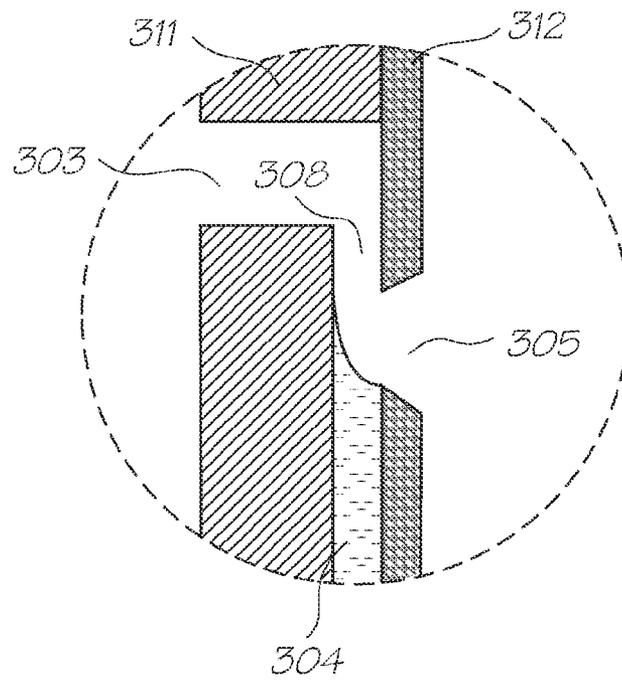


FIG. 13

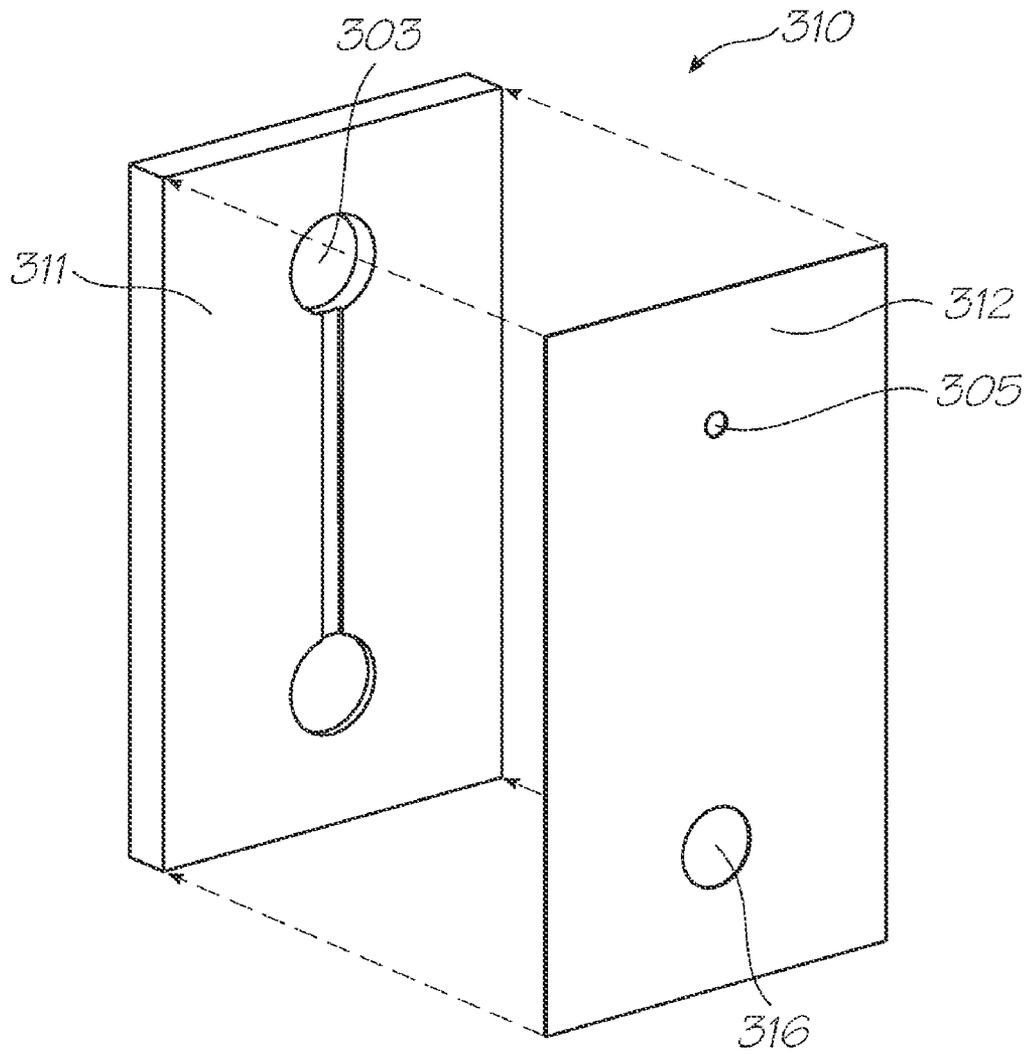


FIG. 14

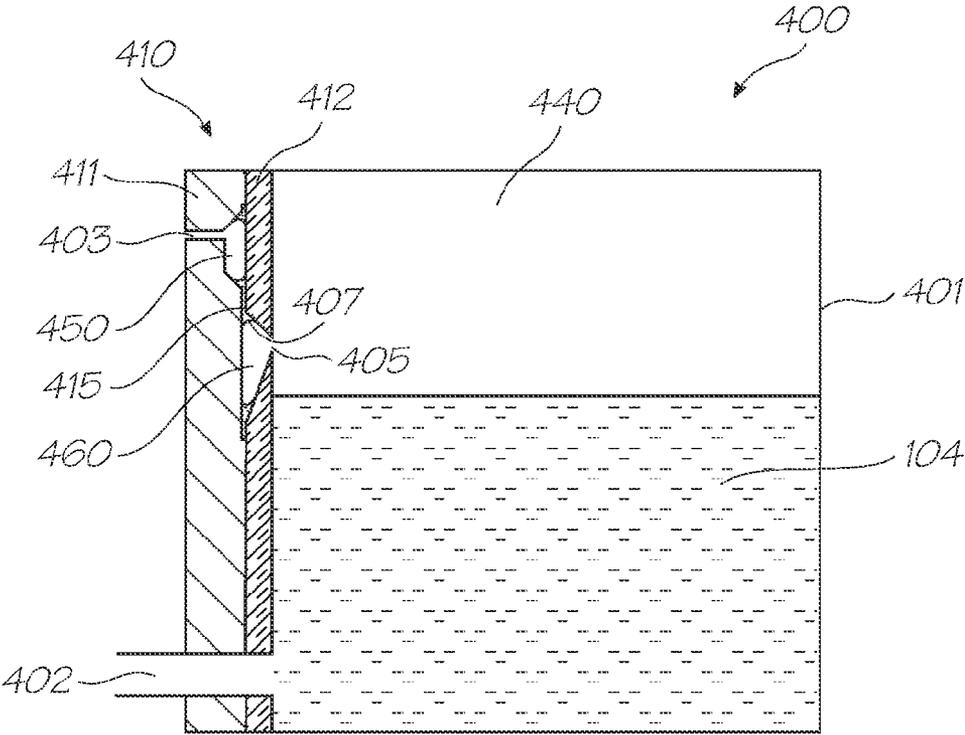


FIG. 15

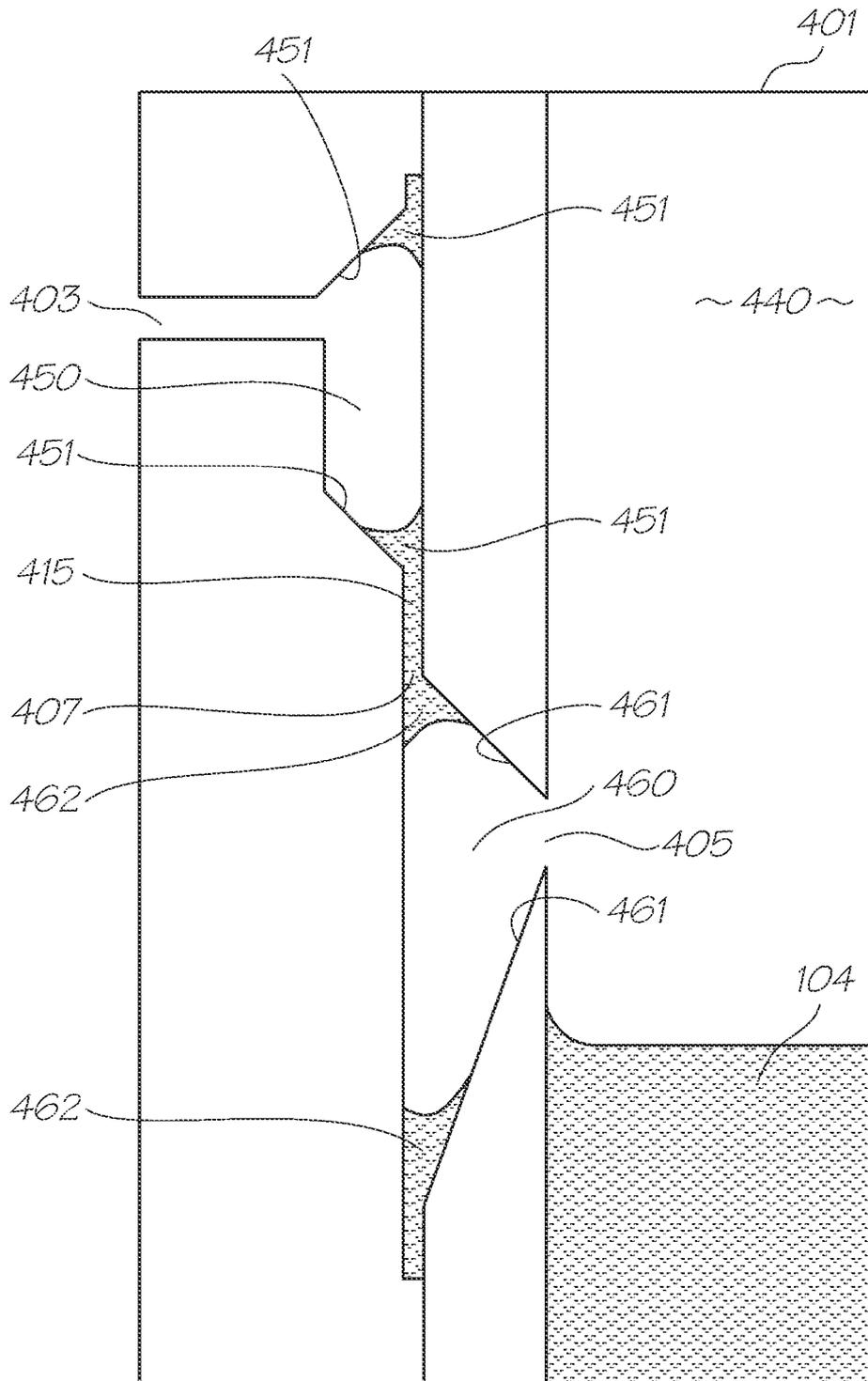


FIG. 16



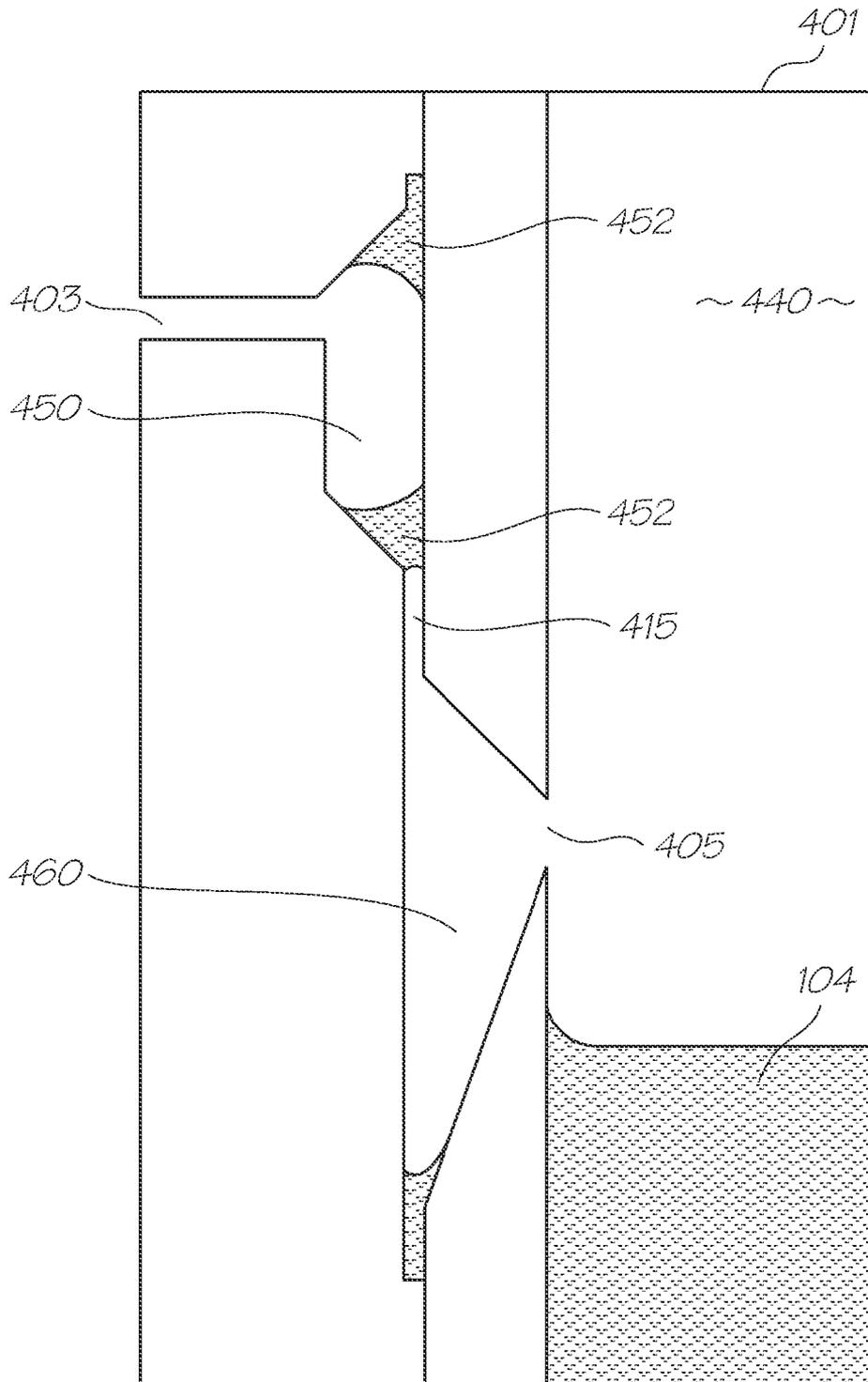


FIG. 18

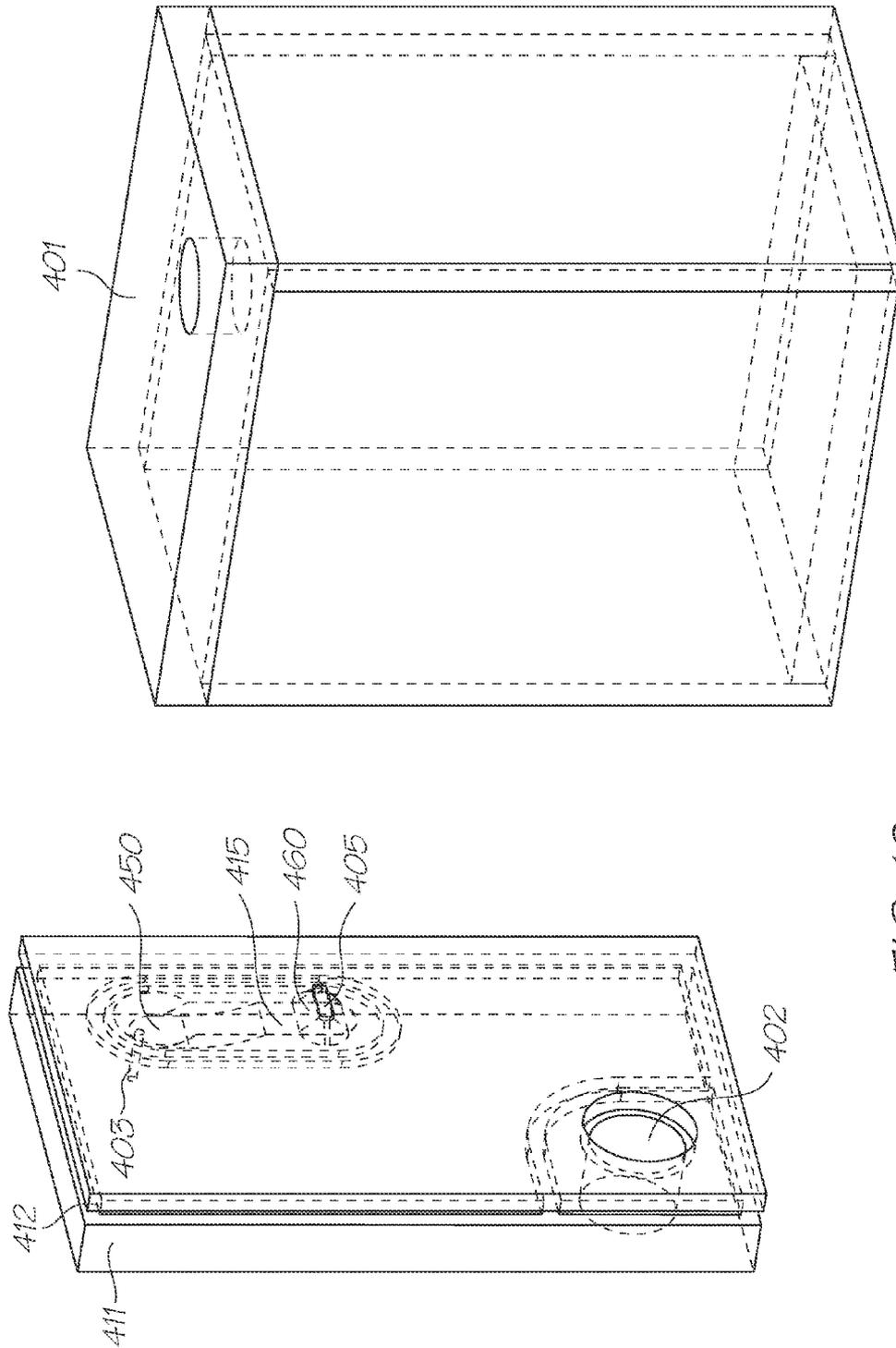


FIG. 19

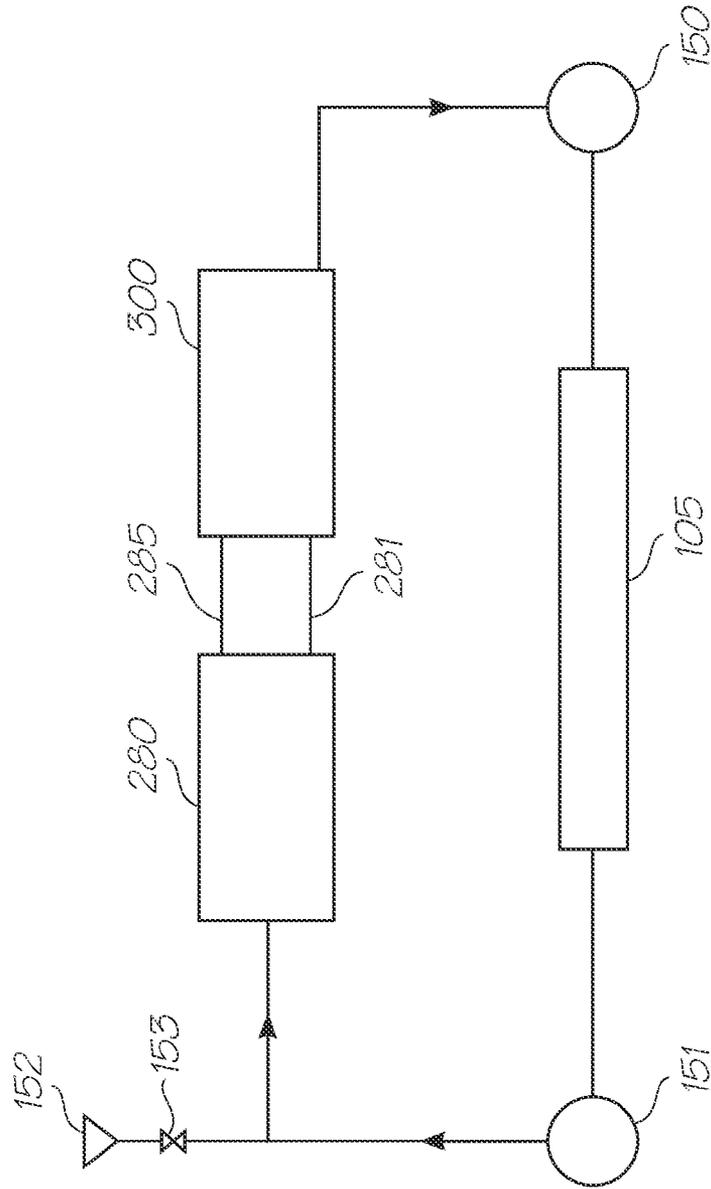


FIG. 20

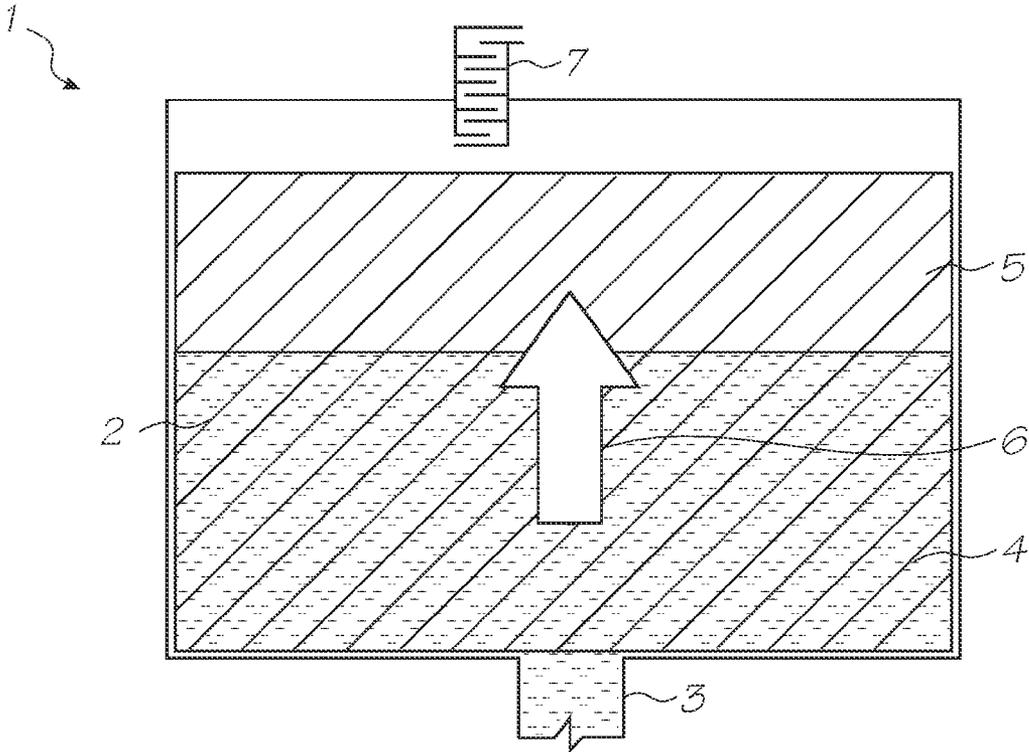


FIG. 21 (PRIOR ART)

**INK CARTRIDGE WITH BUBBLE POINT  
PRESSURE REGULATOR DEFINED IN  
LAMINATED WALL**

**CROSS REFERENCE TO RELATED  
APPLICATION**

The present application is a Continuation of U.S. application Ser. No. 12/859,193 filed Aug. 18, 2010, now issued U.S. Pat. No. 7,926,899 which is a Continuation of U.S. application Ser. No. 11/679,786 filed Feb. 27, 2007, now issued U.S. Pat. No. 7,794,038, which is a Continuation-in-part of U.S. application Ser. No. 11/640,360 filed 18 Dec. 2006, now issued U.S. Pat. No. 7,784,925, all of which is herein incorporated by reference.

**FIELD OF THE INVENTION**

The present invention relates to a pressure regulator for an inkjet printer. It has been developed primarily for generating a negative hydrostatic pressure in an ink supply system supplying ink to printhead nozzles.

**CROSS REFERENCES TO RELATED  
APPLICATIONS**

Various methods, systems and apparatus relating to the present invention are disclosed in the following US patents/patent applications filed by the applicant or assignee of the present invention:

6,988,841	6,641,315	6,786,661	6,808,325	6,712,453
6,460,971	6,428,147	6,416,170	6,402,300	6,464,340
6,612,687	6,412,912	6,447,099	7,249,108	6,566,858
6,331,946	6,246,970	6,442,525	7,346,586	7,685,423
6,374,354	7,246,098	6,816,968	6,757,832	6,334,190
6,745,331	7,249,109	7,197,642	7,093,139	7,509,292
7,685,424	7,743,262	7,210,038	7,401,223	7,702,926
7,716,098	7,090,337	7,461,924	6,913,346	7,156,494
7,032,998	6,994,424	7,001,012	7,004,568	7,040,738
7,188,933	7,131,715	7,261,392	7,182,435	7,097,285
7,083,264	7,147,304	7,156,498	7,201,471	7,549,728
7,364,256	7,258,417	7,293,853	7,328,968	7,270,395
7,461,916	7,510,264	7,334,864	7,255,419	7,284,819
7,229,148	7,258,416	7,273,263	7,270,393	6,984,017
7,347,526	7,357,477	7,465,015	7,364,255	7,357,476
7,758,148	7,284,820	7,341,328	7,246,875	7,322,669
7,445,311	7,452,052	7,455,383	7,448,724	7,441,864
7,637,588	7,648,222	7,669,958	7,607,755	7,699,433
7,658,463	11/518,238	11/518,280	7,663,784	11/518,242
7,506,958	7,472,981	7,448,722	7,575,297	7,438,381
7,441,863	7,438,382	7,425,051	7,399,057	7,695,097
7,686,419	7,753,472	7,448,720	7,448,723	7,445,310
7,399,054	7,425,049	7,367,648	7,370,936	7,401,886
7,506,952	7,401,887	7,384,119	7,401,888	7,387,358
7,413,281	7,530,663	7,467,846	7,669,957	7,771,028
7,758,174	7,695,123	7,798,600	7,604,334	7,857,435
7,708,375	7,695,093	7,695,098	7,722,156	7,703,882
7,510,261	7,722,153	7,581,812	7,641,304	7,753,470
6,227,652	6,213,588	6,213,589	6,231,163	6,247,795
6,394,581	6,244,691	6,257,704	6,416,168	6,220,694
6,257,705	6,247,794	6,234,610	6,247,793	6,264,306
6,241,342	6,247,792	6,264,307	6,254,220	6,234,611
6,302,528	6,283,582	6,239,821	6,338,547	6,247,796
6,557,977	6,390,603	6,362,843	6,293,653	6,312,107
6,227,653	6,234,609	6,238,040	6,188,415	6,227,654
6,209,989	6,247,791	6,336,710	6,217,153	6,416,167
6,243,113	6,283,581	6,247,790	6,260,953	6,267,469
6,588,882	6,742,873	6,918,655	6,547,371	6,938,989
6,598,964	6,923,526	6,273,544	6,309,048	6,420,196
6,443,558	6,439,689	6,378,989	6,848,181	6,634,735
6,299,289	6,299,290	6,425,654	6,902,255	6,623,101

-continued

6,406,129	6,505,916	6,457,809	6,550,895	6,457,812
7,152,962	6,428,133	7,216,956	7,080,895	7,442,317
7,182,437	7,357,485	7,387,368	11/607,976	7,618,124
7,654,641	7,794,056	7,611,225	7,794,055	7,204,941
7,282,164	7,465,342	7,278,727	7,417,141	7,452,989
7,367,665	7,138,391	7,153,956	7,423,145	7,456,277
7,550,585	7,122,076	7,148,345	7,470,315	7,572,327
7,658,792	7,709,633	7,360,865	7,837,775	11/583,942
7,416,280	7,252,366	7,488,051	7,410,250	7,275,811
7,628,468	7,334,874	7,393,083	7,472,984	7,404,625
7,360,871	7,661,793	7,708,372	7,147,792	7,175,774
11/482,988	7,350,903	7,733,535	11/563,684	11/482,967
11/482,966	7,458,659	7,681,000	7,438,371	7,465,017
7,441,862	7,654,636	7,874,659	7,455,376	11/124,198
11/124,196	7,841,713	7,877,111	7,470,019	7,735,993
7,392,950	7,284,921	11/124,151	7,407,257	7,236,271
7,645,022	7,753,517	7,843,484	7,360,880	7,517,046
7,780,288	11/124,174	11/124,172	7,824,031	7,465,047
7,607,774	11/124,182	7,715,036	7,370,932	7,566,182
7,697,159	7,595,904	7,726,764	7,770,995	7,558,962
11/124,181	11/124,187	7,740,347	7,456,994	7,500,268
7,466,444	7,404,616	7,792,298	7,661,813	7,738,862
7,431,449	7,530,446	7,447,908	7,680,512	7,878,645
7,708,203	7,562,973	11/228,531	11/124,179	11/228,500
7,668,540	7,499,765	7,805,162	7,641,115	7,761,090
7,738,919	11/228,507	7,856,225	11/228,505	7,756,526
11/228,504	7,654,444	7,831,244	7,506,802	11/228,518
7,747,280	7,697,714	7,558,563	11/228,506	7,843,595
11/228,526	11/228,527	7,844,257	7,738,674	7,864,360
11/228,509	7,724,399	11/228,515	7,742,755	11/228,520
7,646,503	11/228,514	7,672,664	7,558,599	7,407,797
7,843,596	7,778,666	7,357,311	11/228,492	7,438,215
7,783,323	7,621,442	7,575,172	7,637,424	7,880,911
7,428,986	7,855,805	7,407,092	7,848,777	7,386,535
7,380,709	7,774,025	7,689,249	7,558,598	6,238,115
6,899,480	7,469,829	6,612,240	7,403,796	6,805,049
6,971,313	6,926,455	6,398,344	6,925,935	7,558,597
7,024,995	7,284,852	6,981,809	6,860,664	6,869,172
6,752,549	6,988,845	6,964,533	7,278,795	7,056,038
7,258,067	6,966,636	7,222,941	7,284,925	6,863,379
7,284,822	7,152,972	7,021,843	6,938,992	6,994,425
6,746,105	7,249,904	7,066,577	7,322,757	7,213,907
7,581,819	6,682,176	7,134,741	6,652,074	7,513,615
6,682,174	6,648,453	7,708,387	6,764,166	6,767,077
7,125,103	7,645,026	7,322,681	7,465,032	6,998,062
7,712,884	7,175,260	7,465,041	7,857,428	7,465,037
7,753,496	7,401,910	7,744,195	7,735,971	7,431,432
7,156,508	7,401,890	7,549,735	7,510,267	7,661,800
7,712,869	7,090,336	7,445,317	7,083,271	7,470,010
7,080,894	7,201,469	7,255,423	7,159,972	7,413,283
7,597,425	7,083,257	7,258,422	7,618,121	7,156,489
7,591,533	7,165,834	7,367,649	7,118,192	7,198,355
7,219,980	7,077,505	7,438,385	7,077,504	7,614,724
7,222,938	7,322,672	7,322,676	7,416,274	7,213,906
7,178,901	7,404,621	7,401,894	7,104,629	7,198,354
7,370,939	7,429,095	7,306,324	7,108,353	7,461,919
7,152,959	7,328,972	7,322,673	7,401,405	7,261,401
7,524,021	7,455,392	7,556,360	7,303,930	6,991,322
7,306,325	7,464,465	7,438,388	7,128,400	7,108,355
6,962,402	7,464,466	7,118,197	7,399,071	7,364,269
7,077,493	7,172,270	7,287,836	7,147,308	7,246,886
7,118,198	7,168,790	7,108,356	7,686,429	6,830,318
7,575,298	7,175,261	7,465,035	7,182,439	7,229,155
7,510,269	7,524,034	7,510,270	7,134,743	7,111,926
7,118,202	7,465,036	7,195,342	7,156,484	7,118,201
7,387,369	7,210,768	7,018,021	7,134,744	7,468,139
7,128,402	7,229,156	7,431,433	7,802,871	7,134,745
7,284,839	7,246,885	7,258,427	7,484,832	7,467,855
7,401,901	7,520,594	7,588,321	7,419,249	7,533,970
7,278,716	7,506,968	7,246,876	7,431,431	7,264,645
7,556,350	7,328,978	7,293,858	7,147,306	7,261,394
6,813,039	7,377,623	7,721,948	7,448,729	6,825,945
7,330,974	7,350,236	7,784,915	7,038,797	7,334,876
6,816,274	7,102,772	7,068,382	6,987,506	6,728,000
7,079,712	7,088,459	7,707,082	6,622,999	6,681,045
6,789,194	6,980,318	6,644,642	6,502,614	6,439,706
7,062,651	6,549,935	7,173,722	6,727,996	6,591,884
6,870,966	6,669,385	7,295,332	6,789,191	6,428,155
6,785,016	6,832,717	6,760,119	6,737,591	6,987,573
7,233,320	6,830,196	7,818,519	6,822,639	7,456,820

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6,290,349	7,106,888	7,123,239	7,592,829	6,957,768
7,399,043	7,055,739	7,165,824	7,152,942	7,573,301
7,377,608	7,096,137	7,170,499	7,278,034	7,188,282
7,278,697	7,181,572	7,783,886	7,121,639	7,707,621
7,523,111	7,070,098	7,660,998	7,519,772	7,302,592
7,369,270	7,171,323	6,394,573	7,360,131	6,805,419
7,770,008	6,977,751	6,795,215	7,457,001	7,454,638
6,747,760	7,831,827	7,092,112	6,398,332	7,270,391
6,622,923	6,986,560	7,328,115	7,551,324	7,192,106
7,374,266	7,173,739	7,388,689	6,859,289	7,195,328
7,222,780	7,735,944	7,525,677	7,448,707	6,921,144
7,600,843	7,182,422	7,390,071	7,427,117	7,093,989
7,008,033	7,607,757	7,328,956	7,484,831	7,188,928
7,549,715	7,571,906	7,281,777	10/854,498	7,557,941
7,517,036	7,275,805	7,281,330	7,866,778	7,267,417
7,163,345	7,758,143	7,832,842	7,377,609	7,243,193
7,290,852	11/544,774	7,757,086	7,566,111	7,252,353
7,819,494	7,631,190	7,604,321	7,322,666	7,425,048
7,314,261	7,780,256	11/544,772	7,452,055	7,845,747
7,681,970	7,549,718	7,413,288	7,384,128	7,448,739
7,722,163	7,722,161	7,266,661	7,448,735	7,465,033
7,722,185	7,470,002	7,735,955	11/544,764	7,461,922
7,465,042	7,547,088	7,438,399	7,425,050	11/544,766
7,632,032	7,465,020	7,703,903	7,461,910	7,287,846
7,425,047	7,681,876	7,475,961	7,234,802	7,611,239
7,201,470	7,475,963	7,201,468	7,780,161	7,097,291
7,448,734	7,083,272	7,467,853	7,367,647	7,360,868
7,441,880	7,303,255	7,328,973	7,270,494	7,293,861
7,258,432	7,364,264	7,645,025	7,311,382	7,758,038
7,621,620	7,374,355	7,328,985	7,547,092	7,384,135
7,364,263	7,407,262	7,198,352	7,331,663	7,303,251
7,311,381	7,156,511	7,364,257	7,232,208	7,249,822
7,344,232	7,681,967	7,083,273	7,416,287	7,669,961
7,350,896	7,360,861	7,524,043	7,513,598	7,303,268
7,303,252	7,322,684	7,537,309	7,284,816	7,121,655
7,249,833	7,390,075	7,399,072	7,429,096	7,322,671
7,311,387	7,357,492	7,488,052	7,490,927	7,322,685
7,441,865	7,427,121	7,255,430	7,470,007	7,566,106
7,393,076	7,357,496	7,360,860	7,431,424	7,524,016
7,328,984	7,331,661	7,513,663	7,331,660	7,367,650
7,357,493	7,585,054	7,380,902	7,661,803	7,270,405
7,431,440	7,390,080	7,441,882	7,350,913	11/013,881
7,588,301	7,465,045	7,470,006	7,527,353	7,347,534
7,083,262	7,300,140	7,607,756	7,469,990	7,637,602
7,556,364	7,178,899	7,284,845	7,070,258	7,431,443
6,988,789	7,524,023	6,488,358	7,380,910	7,073,892
7,645,034	7,178,903	7,645,033	6,364,461	7,469,989
7,497,555	7,431,446	7,147,302	7,198,346	6,457,813
7,467,863	6,712,986	7,398,597	6,485,123	7,325,918
6,550,896	7,467,852	6,425,658	7,036,912	6,505,912
7,380,906	6,698,867	7,841,708	6,454,396	7,524,026
6,814,429	6,425,657	6,513,908	7,083,261	6,447,100
6,981,757	6,435,664	6,439,694	7,077,508	7,192,119
6,425,651	6,488,361	6,488,359	6,471,336	6,672,708
7,258,425	6,679,584	6,464,325	6,527,374	6,412,914
7,240,992	7,021,746	6,935,724	7,381,340	6,652,052
6,623,108	7,255,424	6,378,990	6,874,866	6,435,667
6,988,787	6,582,059	7,407,261	6,540,331	7,066,578
6,857,724	6,994,420	6,672,706	7,132,056	6,439,695
7,216,957	6,927,786	7,399,063	6,899,415	6,890,059
6,488,362	6,966,633	6,830,316	6,916,082	7,086,720
7,044,584	6,540,332	6,860,590	7,101,023	6,969,153
7,159,965	7,011,390	7,207,654	7,125,102	7,461,923
6,786,574	6,786,570	7,104,631	6,644,767	7,140,720
7,179,395	7,066,575	6,979,075	7,334,877	7,267,424
7,014,785	6,905,620	7,416,275	6,824,252	7,284,326
7,137,686	7,172,265	7,028,474	7,331,101	6,986,202
6,938,994	6,848,780	7,566,110	7,207,656	7,364,270
7,008,041	6,923,583	6,832,828	6,932,459	7,131,717
7,413,671	7,182,436	7,192,120	7,246,881	7,380,339
7,284,837	6,998,278	7,152,949	7,182,431	7,032,992
6,921,221	7,637,594	7,077,588	7,571,983	7,284,833
7,048,868	7,207,657	7,032,997	7,337,532	7,004,563
7,219,427	7,556,358	7,374,695	7,134,740	7,147,303
6,918,707	6,886,917	7,326,357	6,669,332	7,168,167
6,830,395	7,322,680	7,066,574	7,284,834	6,808,253
7,152,944	7,073,881	7,101,020	7,055,934	7,188,935
7,052,114	6,945,630	6,959,982	6,641,255	7,524,032
6,953,295	6,976,751	6,663,225	7,008,046	7,155,823
6,783,217	7,168,789	7,419,250	6,827,428	7,080,893

-continued

6,959,981	6,786,573	7,252,367	7,067,067	7,001,007
7,226,147	6,880,918	6,988,788	6,666,543	6,929,352
7,175,775	6,880,914	7,270,492	7,189,334	7,347,952
5 6,799,835	7,083,263	6,834,939	7,195,339	7,470,003
6,863,378	6,929,350	6,776,476	7,226,145	7,086,709
6,921,150	7,156,495	7,147,305	6,824,251	7,055,933
6,840,600	7,159,968	7,367,729	7,270,399	6,938,991
7,152,960	7,140,719	7,093,928	7,350,901	7,284,836
7,004,566	6,886,918	7,144,098	7,229,154	7,147,791
10 7,111,925	7,325,904	7,290,856	7,441,867	7,022,250
7,144,519	7,278,711	6,866,369	7,341,672	7,204,582
7,431,429	7,147,307	6,913,347	7,086,721	7,401,895

The disclosures of these applications and patents are incorporated herein by reference. Some of the above applications have been identified by their filing docket number, which will be substituted with the corresponding application number, once assigned.

## BACKGROUND OF THE INVENTION

The inkjet printheads described in the above cross referenced documents typically comprise an array of nozzles, each nozzle having an associated ink ejection actuator for ejecting ink from a nozzle opening defined in a roof of a nozzle chamber. Ink from an ink cartridge or other reservoir is fed to the chambers where the ejection actuators force droplets of ink through the nozzle opening for printing. Typically, an ink cartridge is a replaceable consumable in an inkjet printer.

Ink may be drawn into each nozzle chamber by suction generated after each drop ejection and by the capillary action of ink supply channels having hydrophilic surfaces (e.g. silicon dioxide surface). During periods of inactivity, ink is retained in the nozzle chambers by the surface tension of an ink meniscus pinned across a rim of each nozzle opening. If the ink pressure is not controlled, it may become positive with respect to external atmospheric pressure, possibly by thermal expansion of the ink, or a tipping of the printer that elevates the ink above the level of the nozzles. In this case the ink will flood onto the printhead surface. Moreover, during active printing, ink supplied through the ink supply channels has a momentum, which is sufficient to surge out of the nozzles and flood the printhead face once printing stops. Printhead face flooding is clearly undesirable in either of these scenarios.

To address this problem, many printhead ink supply systems are designed so that a hydrostatic pressure of ink at the nozzles is less than atmospheric pressure. This causes the meniscus across the nozzle openings to be concave or drawn inwards. The meniscus is pinned at nozzle openings, and the ink cannot freely flow out of the nozzles, both during inactive periods. Furthermore, face flooding as a result of ink surges are minimized.

The amount of negative pressure in the chambers is limited by two factors. It cannot be strong enough to de-prime the chambers (i.e. suck the ink out of the chambers and back towards the cartridge). However, if the negative pressure is too weak, the nozzles can leak ink onto the printhead face, especially if the printhead is jolted. Aside from these two catastrophic events requiring some form of remediation (e.g. printhead maintenance or re-priming), a sub-optimal hydrostatic ink pressure will typically cause an array of image defects during printing, with an appreciable loss of print quality. Accordingly, inkjet printers may have a relatively narrow window of hydrostatic ink pressures, which must be achieved by a pressure regulator in the ink supply system.

Typically, ink cartridges are designed to incorporate some means for regulating hydrostatic pressure of ink supplied therefrom. To establish a negative pressure, some cartridges use a flexible bag design. Part of the cartridge has a flexible bag or wall section that is biased towards increasing the ink storage volume. U.S. Ser. No. 11/014,764 and U.S. Ser. No. 11/014,769 (listed above in the cross referenced documents) are examples of this type of cartridge. These cartridges can provide a negative pressure, but tend to rely on excellent manufacturing tolerances of an internal leaf spring in the flexible bag. Further, the requirement of an internal biasing means in a flexible bag presents significant manufacturing difficulties.

Another means of generating a negative ink pressure via the ink cartridge is shown in FIG. 21. A piece of foam or porous material 2 is placed in the cartridge 1 over the outlet 3. The foam 2 has a section that is saturated with ink 4, and a section 5 that may be wet with ink, but not saturated. The top of the cartridge 1 is vented to atmosphere through the air maze 7. Capillary action (represented by arrow 6) draws the ink from the saturated section 4 into the unsaturated section 5. This continues until it is balanced by the weight of the increased hydrostatic pressure, or 'head' of ink drawn upwards by the capillary action 6. The hydrostatic pressure at the top of the saturated section 4 is less than atmospheric because of capillary action into the unsaturated section 5. From there, the hydrostatic pressure increases towards the outlet 3, and if connected to the printhead (not shown), it continues to increase down to the nozzle openings (assuming they are the lowest points in the printhead). By setting the proportion of saturated foam to unsaturated foam such that the hydrostatic pressure of the ink at the nozzle is less than atmospheric, the ink meniscus will form inwardly.

However, ink cartridges comprising foam inserts are generally unsuitable for high speed printing (e.g. print speeds of one page every 1-2 seconds) using the Applicant's pagewidth printheads, which print at up to 1600 dpi. In such high speed printers, there are a large number of nozzles having a higher firing rate than traditional scanning printers. Therefore the ink flow rate out of the cartridge is much greater than that of a scanning printhead. The hydraulic drag caused by the foam insert can starve the nozzles and retard the chamber refill rate. More porous foam would have less hydraulic drag but also much less capillary force. Further, accurate pressure control requires equally accurate control over the internal void dimensions, which is difficult to achieved by the stochastically formed void structures of most foam materials. Accordingly, porous foam inserts are not considered to be a viable means for controlling ink pressure at high ink flow rates.

As an alternative (or in addition) to ink cartridges having integral pressure regulators, the ink supply system may comprise a pressure regulator in the ink line between the printhead and an ink reservoir. The present Applicant's previously filed U.S. application Ser. Nos. 11/293,806, filed on Dec. 5, 2005) and 11/293,842, filed on Dec. 5, 2005), the contents of which are herein incorporated by reference, describe an in-line pressure regulator comprising a diaphragm and biasing mechanism. This mechanical arrangement is used to generate a negative hydrostatic ink pressure at the printhead. However, this type of mechanical pressure regulator has the drawback of requiring extremely fine manufacturing tolerances for a spring, which opens and closes the diaphragm in response to fluctuations in ink pressure upstream and downstream of the diaphragm. In practice, this mechanical system of pressure control makes it difficult to implement in an ink supply system required to maintain a constant negative hydrostatic ink pressure within a relatively narrow pressure range.

It would therefore be desirable to provide a pressure regulator, which is suitable for maintaining a hydrostatic ink pressure within a relatively narrow pressure range. It would fur-

ther be desirable to provide a pressure regulator, which is suitable for use at relatively high ink flow rates. It would further be desirable to provide a pressure regulator, which is simple in construction and which does not require a plethora of moving parts manufactured with high tolerances. It would further be desirable to provide a pressure regulator, which does not leak ink as a result of pressure fluctuations during temperature cycling.

#### SUMMARY OF THE INVENTION

In a first aspect, there is provided an ink pressure regulator for regulating a hydrostatic pressure of ink supplied to an inkjet printhead, said regulator comprising:

an ink chamber having an ink outlet for fluid communication with the printhead via an ink line;

an air inlet;

a regulator channel having a first end communicating with the air inlet and a second end communicating with a headspace of the chamber, said second end defining a bubble outlet; and

a wetting system for maintaining at least some liquid in said regulator channel, thereby ensuring that air entering the headspace first passes through said liquid;

wherein said regulator channel is dimensioned to control a Laplace pressure of air bubbles drawn from said bubble outlet as result of supplying ink to the printhead, thereby regulating a hydrostatic pressure of the ink.

Optionally, said wetting system is fluidically isolated from a reservoir of ink in said ink chamber.

Optionally, said wetting system comprises a wetting chamber in fluid communication with said regulator channel.

Optionally, said wetting system comprises a first wetting chamber connected to said first end and a second wetting chamber connected to said second end.

Optionally, each wetting chamber is configured such that, in use, a volume of liquid is retained therein by surface tension. Optionally, each wetting chamber is configured such that liquid is pinned into edge regions thereof.

Optionally, an edge region of each wetting chamber is connected to said regulator channel.

Optionally, an annulus of liquid is retained in said edge regions.

Optionally, each wetting chamber is generally chamfered such that said edge regions comprise at least two chamber walls meeting at an acute angle.

Optionally, said first wetting chamber is open to atmosphere via said air inlet.

Optionally, said second wetting chamber has a vent opening into said headspace.

Optionally, said wetting chambers and said regulator channel together retain a substantially constant volume of liquid.

Optionally, said liquid is transferable between said wetting chambers via said regulator channel.

Optionally, during idle periods, a positively pressurized headspace forces liquid to transfer from said second wetting chamber to said first wetting chamber.

Optionally, positively pressurized air in said headspace escapes via said air inlet, having first passed through said liquid.

Optionally, said liquid is ink.

Optionally, a depth of said regulator channel is dimensioned such that, during printing, a hydrostatic pressure of said ink is at least 10 mm H<sub>2</sub>O less than atmospheric pressure.

Optionally, a depth of said regulator channel is dimensioned such that, during printing, a hydrostatic pressure of said ink is at least 100 mm H<sub>2</sub>O less than atmospheric pressure.

Optionally, a depth of said regulator channel is less than 200 microns.

Optionally, said pressure regulator defines an ink cartridge for an inkjet printer.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Optional embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

FIG. 1 is a schematic side section of a pressure regulator according to the present invention having a needle-like bubble outlet;

FIG. 2 is magnified view of the bubble outlet shown in FIG. 1;

FIG. 3A is a schematic perspective view of a slot-shaped bubble outlet;

FIG. 3B shows the bubble outlet of FIG. 3A partially blocked with debris;

FIG. 4 is a schematic side section of a pressure regulator according to the present invention having a slot-shaped bubble outlet;

FIG. 5 is a magnified view of the bubble outlet shown in FIG. 4;

FIG. 6 is an exploded perspective view of the air intake plate shown in FIG. 4;

FIG. 7 is a perspective view of an alternative air intake plate with protective moat;

FIG. 8 is an exploded perspective view of an alternative tri-layered air intake plate;

FIG. 9 is a schematic side section of the pressure regulator shown in FIG. 4 connected to a separate ink cartridge;

FIG. 10 is a schematic side section of a pressure regulator with bubble outlet positioned for bubbling air bubbles into a headspace and capillary supply of ink to the bubble outlet;

FIG. 11 is a magnified view of the bubble outlet shown in FIG. 10 during printing;

FIG. 12 is a magnified view of the bubble outlet shown in FIG. 10 during an idle period;

FIG. 13 is a magnified view of the bubble outlet shown in FIG. 10 during an instant when the headspace is venting after having been positively pressurized;

FIG. 14 is an exploded perspective view of the air intake plate shown in FIG. 10;

FIG. 15 is a schematic side section of a pressure regulator with a fluidically isolated wetting system for a regulator channel;

FIG. 16 is a magnified view of the regulator channel shown in FIG. 15 during an idle period;

FIG. 17 is a magnified view of the regulator channel shown in FIG. 15 during printing;

FIG. 18 is a magnified view of the regulator channel shown in FIG. 15 when the headspace is positively pressurized;

FIG. 19 is a cutaway perspective view of the pressure regulator shown in FIG. 15;

FIG. 20 shows schematically an ink supply system according to the present invention; and

FIG. 21 is a schematic side section of a prior art ink cartridge incorporating a foam insert.

#### DETAILED DESCRIPTION OF OPTIONAL EMBODIMENTS

##### Pressure Regulator with Circular Bubble Outlet

FIG. 1 shows the simplest form of the present invention, for the purposes of explaining the basic operating principle of the pressure regulator. In FIG. 1, there is shown a pressure regulator 100 comprising an ink chamber 101 having an ink outlet 102 and air inlet 103. The ink chamber 101 is otherwise

sealed. The ink outlet 102 is for supplying ink 104 to a printhead 105 via an ink line 106. A bubble outlet 107 is connected to the air inlet 103 via an air channel 108.

When ink 104 is drawn from the ink chamber 101 by the printhead 105, the displaced volume of ink must be balanced with an equivalent volume of air, which is drawn into the chamber via the air inlet 103. The bubble outlet 107, which is positioned below the level of ink, ensures that the air enters the chamber 101 in the form of air bubbles 109. The dimensions of the bubble outlet 107 determine the size of the air bubbles 109 entering the chamber 101.

As shown in FIG. 2, the air channel 108 takes the form of a simple cylindrical channel, so that the bubble outlet 107 is defined by a circular opening at one end of the cylindrical channel. Accordingly, any air passing through the channel must at some point be bounded by a liquid surface with radius of curvature not greater than the internal radius of the channel.

During printing, the nozzles on the printhead 105 effectively act as a pump, drawing ink from the ink chamber 101 with each drop ejection. If the ink chamber were left freely open to atmosphere with an air vent (as in some prior art ink cartridges), the hydrostatic ink pressure of the ink supplied to the printhead would be simply be determined by the elevation of the ink reservoir above or below the printhead. However, in the ink chamber 101, each time a microscopic volume of ink is drawn from the chamber 101, it must overcome the pressure inside an air bubble 109 forming at the bubble outlet 107. Once the pumping effect of the nozzles generates sufficient pressure to match the pressure inside the air bubble 109 forming at the bubble outlet 107, then the air bubble can escape into the reservoir of ink 104 and ink can flow from the chamber 101 via the ink outlet 102.

Therefore, the air bubbles 109 forming at the bubble outlet 107 provide a back pressure against the pumping effect of the printhead nozzles. In other words, the effect of the bubble outlet 107 is to generate a negative hydrostatic ink pressure in the ink supply system.

The pressure inside the spherical air bubbles 109 is determined by the well-known Laplace equation:

$$\Delta P = 2\gamma/r$$

where:

$\Delta P$  is the difference in pressure between the inside of the air bubble and the ink;

$r$  is the radius of the air bubble; and

$\gamma$  is the surface tension of the ink-air interface.

The size of the air bubbles 109 can be varied by varying the dimensions of the bubble outlet 107. Therefore, the dimensions of the bubble outlet 107 provides a means of establishing a predetermined negative hydrostatic pressure of ink supplied to the printhead 105. Smaller bubble outlet dimensions provide a larger negative hydrostatic ink pressure by virtue of generating smaller air bubbles having a higher Laplace pressure.

In the pressure regulator 100 described above, the air channel 108 is a small-bored cylinder (e.g. hypodermic needle) having a circular opening defining the bubble outlet 107. However, a significant problem with this design is that the circular bubble outlet 107 has a very small area (of the order of about 0.01 mm<sup>2</sup>) and is susceptible to blockages by contaminants in the ink. It would be desirable to increase the area of the bubble outlet 107 so that it is more robust, even if there are contaminants in the ink.

##### Pressure Regulator with Slot-Shaped Bubble Outlet

As shown in FIG. 3A, an improved design of bubble outlet 107 uses a slot 110, as opposed to a circular opening. The slot has a length dimension L and a width dimension W. The air

bubbles **109** exiting the slot typically have a cylindrical front extending across the length of the slot. As explained below, the curvature of the air bubbles **109** exiting the slot and, hence, the Laplace pressure of the air bubbles, is determined primarily by the width dimension.

For non-spherical bubbles, the Laplace pressure is given by the expression:

$$\Delta P = \gamma/r_1 + \gamma/r_2$$

where:

$\Delta P$  is the difference in pressure between the inside of the air bubble and the ink;

$r_1$  is the radius of a width dimension of the air bubble;

$r_2$  is the radius of a length dimension of the air bubble;

$\gamma$  is the surface tension of the ink-air interface.

In practice, the length of the slot is much greater than the width ( $r_2 \gg r_1$ ), and so the Laplace pressure of the air bubbles exiting the slot with a cylindrical front becomes:

$$\Delta P = \gamma/r_1 \text{ or } 2\gamma/W (\text{since } W = 2r_1)$$

It will therefore be appreciated that the width of the slot **110** is the only critical dimension controlling the Laplace pressure of the air bubbles **109** exiting the slot.

FIG. **3B** shows a hypothetical scenario where a piece of debris **111** has become stuck to the slot **110**. However, unlike the case of a circular opening, the slot **110** is still able to control the critical curvature of bubbles exiting the slot. An air bubble **109** having a cylindrical front can still exit the slot **110** as shown in FIG. **3B**. Thus, the slot **110** provides a more robust design for the bubble outlet **107**, whilst still maintaining excellent control of the hydrostatic ink pressure.

In the embodiments discussed so far, the dimensions of the air channel **108** mirror the dimensions of the bubble outlet **107**. This is not an essential feature of the regulator and, in fact, may adversely affect the efficacy of the regulator, particularly at high flow rates. The inherent viscosity of air can cause a significant flow resistance or hydraulic drag in the air channel **108**. According to Poiseuille's equation, flow rate has an  $r^4$  relationship with pipe radius  $r$ . Hence, the problem of flow resistance is exacerbated in channels having very small radii.

In the present invention, a critical dimension of the bubble outlet **107** is optionally less than about 200 microns, or optionally less than about 150 microns, or optionally less than about 100 microns, or optionally less than about 75 microns or optionally less than about 50 microns. Optionally, the critical dimension of the bubble outlet may be in the range of 10 to 50 microns or 15 to 40 microns. By "critical dimension" it is meant the dimension of the bubble outlet determining the curvature and, hence, the Laplace pressure of the air bubbles.

Such dimensions are necessary to provide the desired negative hydrostatic ink pressure, which is optionally at least 10 mm H<sub>2</sub>O, or optionally at least 30 mm H<sub>2</sub>O, or optionally at least 50 mm H<sub>2</sub>O for a photo-sized printhead. For an A4-sized printhead, the desired negative hydrostatic ink pressure is optionally at least 100 mm H<sub>2</sub>O, or optionally at least 200 mm H<sub>2</sub>O, or optionally at least 300 mm H<sub>2</sub>O. Optionally, the negative hydrostatic pressure may be in the range of 100 to 500 mm H<sub>2</sub>O or 150 to 450 mm H<sub>2</sub>O.

The air channel **108**, having a width of, say, less than 200 microns, generates significant flow resistance for air entering the channel. If air is unable to pass through the channel **108** at the same flow rate as ink is supplied to the printhead **105**, then a catastrophic deprive of the printhead would result at high print-speeds.

Accordingly, it is desirable to configure the air channel **108** so that each cross-sectional dimension of the air channel is

larger than the critical dimension of the bubble outlet **107**. So, for the slot-shaped bubble outlet **107** shown in FIG. **3A**, the air channel **108** should optionally have each cross-sectional dimension greater than the width  $W$  of the slot **110**.

However, it is important that the volume of the air channel **108** is not too large. When the printhead **105** is idle, ink may rise up the air channel **108** by capillary action. This volume of ink must be pulled through the air channel **108** by the printhead **105** before air bubbles **109** are drawn into the ink chamber **101** and the optimal hydrostatic ink pressure for printing is reached. Hence, a volume of ink drawn into the air channel **108** by capillary action during idle periods will be wasted, since it cannot be printed with optimal print quality.

The capillary volume of ink increases with the radius of the air channel. Accordingly, the cross-sectional dimensions (e.g. radius) of the air channel **108** should optionally not be so large that the maximum capillary volume exceeds about 0.1 mL of ink, which is effectively a dead volume of ink. Optionally, the maximum capillary volume of ink in the air channel is less than about 0.08 mL, or optionally less than about 0.05 mL, or optionally less than about 0.03 mL.

FIG. **4** shows an alternative ink pressure regulator **200** having a bubble outlet **207** and air channel **208** with the abovementioned design considerations taken into account. The pressure regulator **200** comprises an ink chamber **201** having an ink outlet **102**. One sidewall of the ink chamber **201** is defined by a laminated air intake plate **210** comprising first and second planar layers **211** and **212**. The first and second layers **211** and **212** have respective first and second faces **221** and **222** which cooperate to define the air inlet **203**, the air channel **208** and the bubble outlet **207**. The air inlet **203** may optionally comprise an air filter (not shown) for filtering particulates from air drawn into the ink chamber **201**.

The ink chamber **201** also comprises a one-way pressure release valve **219**, which is normally closed during operation of the pressure regulator **200**. The valve **219** is configured to release any positive pressure in a headspace **240** above the ink **104**, which may, for example, result from thermal expansion of a volume of air trapped in the headspace during typical day/night temperature fluctuations. A positive pressure in the headspace **240** is undesirable because it forces ink up the air channel **208** and out of the air inlet **203**, leading to appreciable ink losses from the chamber **201**.

Referring to FIG. **6**, the first layer **211** of the air intake plate **210** has an air inlet opening **213** defined therethrough and an elongate recess **214** in the form of a groove defined in the first face **221**. The elongate recess **214** extends from the air inlet opening **213** to a recessed terminus region. The recessed terminus region comprises a circular recess **216** which has a relatively shallow depth compared to the elongate recess **214**. Still referring to FIG. **6**, the second layer **212** has a bubble vent opening **217** defined therethrough. As will be appreciated from FIGS. **4** and **6**, when the first and second faces **221** and **222** are laminated together, the recesses and openings cooperate to define the air inlet **203**, the air channel **208** and the bubble outlet **207**.

FIG. **5** shows in detail a bubble outlet region **220** of the air intake plate **210**. The circular recess **216**, being shallower than the elongate recess **214**, defines a constriction **218** in the air channel **108**. This constriction **218**, defined by the depth of the circular recess **216** in the first face **221**, defines a critical width dimension for the bubble outlet **207**. The bubble outlet **207** therefore takes the form of an annular slot with a length of the slot being defined by a circumference of the bubble vent opening **217** in the second layer **212**.

An advantage of having an annular slot is that it maximizes the length of the slot, thereby improving the robustness of the

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bubble outlet 207 to particulate contamination. An advantage of having a relatively deep elongate recess 214 is that it minimizes flow resistance in the air channel 108 defined by cooperation of the recess 214 and the second face 222. Typically, the elongate recess 214 has a depth in the range of 0.2 to 1 mm or 0.2 to 0.5 mm, and a width in the range of 0.5 to 2 mm or 0.7 to 1.3 mm.

Still referring to FIG. 5, it can be seen that inner faces 231 of the bubble vent opening 217 are beveled so as to optimize escape of bubbles from the bubble outlet 207.

Referring to FIG. 7, the first layer 211 of the air intake plate 210 may have a moat 230 defined therein. The moat 230 surrounds the features defined in the first layer 211 and, importantly, protects the elongate recess 214 and circular recess 216 from any adhesive during the lamination process. The wicking of any excess adhesive between the first and second faces 221 and 222 is arrested by the moat 230 as capillary action can only transport liquids into of structures ever decreasing dimensions, and any path across the moat includes a region of increasing dimension. This prevents blocking of the air inlet channel 208 or the bubble outlet opening 207, which are defined by lamination of the two layers. Hence, the moat 230 is a feature, which facilitates manufacture of the air intake plate 210.

Of course, it will be appreciated that the air intake plate may take many different forms and may, for example, be defined by cooperation of more than two laminated layers. FIG. 8 shows an air intake plate 250 defined by cooperation of three layers. A first layer 251 has an air inlet opening 252 defined therethrough; a second layer 253 has a bubble vent opening 254 defined therethrough; and a third film layer 255 is sandwiched between the first and second layers. The film layer 255 has an air channel opening 256 defined therethrough, so that when the three layers are laminated together a fluidic path is defined from an air inlet to the bubble vent. The thickness of the film layer 255 defines the depth of the air channel and the critical dimension of the bubble outlet at the terminus of the air channel.

Tables 1 to 4 below show measured hydrostatic ink pressures for the pressure regulator 200 shown in FIGS. 4 to 6. Four pressure regulators were constructed having different critical dimensions of the bubble outlet 207. Dynamic pressure measurements were made at various flow rates and static pressure measurements were made by stopping the flow of ink. The dynamic pressure loss is the difference between the dynamic regulating pressure and the static regulating pressure.

TABLE 1

35 micron bubble outlet			
Flow Rate (ml/sec)	Dynamic Regulating Pressure (mm H <sub>2</sub> O)	Static Regulating Pressure (mm H <sub>2</sub> O)	Dynamic Pressure Loss (mm H <sub>2</sub> O)
0.05	-203	-178	-25
0.04	-196	-175	-21
0.03	-194	-178	-16
0.02	-189	-173	-16
0.01	-185	-175	-10
0.005	-172	-165	-7
-174 (Average)			

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TABLE 2

70 micron bubble outlet			
Flow Rate (ml/sec)	Dynamic Regulating Pressure (mm H <sub>2</sub> O)	Static Regulating Pressure (mm H <sub>2</sub> O)	Dynamic Pressure Loss (mm H <sub>2</sub> O)
0.05	-110	-84	-26
0.04	-104	-79	-25
0.03	-100	-84	-16
0.02	-91	-79	-12
0.01	-84	-83	-1
0.005	-80	-76	-4
-81 (Average)			

TABLE 3

105 micron bubble outlet			
Flow Rate (ml/sec)	Dynamic Regulating Pressure (mm H <sub>2</sub> O)	Static Regulating Pressure (mm H <sub>2</sub> O)	Dynamic Pressure Loss (mm H <sub>2</sub> O)
0.05	-65	-38	-27
0.04	-65	-44	-21
0.03	-56	-40	-16
0.02	-51	-38	-13
0.01	-43	-38	-5
0.005	-38	-36	-2
-39 (Average)			

TABLE 4

140 micron bubble outlet			
Flow Rate (ml/sec)	Dynamic Regulating Pressure (mm H <sub>2</sub> O)	Static Regulating Pressure (mm H <sub>2</sub> O)	Dynamic Pressure Loss (mm H <sub>2</sub> O)
0.05	-60	-32	-28
0.04	-56	-34	-22
0.03	-54	-36	-18
0.02	-51	-37	-14
0.01	-38	-34	-4
0.005	-34	-31	-3
-34 (Average)			

Excellent control of ink pressure was achievable simply by varying the dimensions of the bubble outlet.

Moreover, the pressure measurements confirmed that the air bubbles were being generated in accordance with the Laplace equation. The average static regulating pressures were found to obey the equation:

$$P = -0.0067/W + 18.3$$

where:

P is the average static regulating pressure in millimeters of water head;

W is the width of the bubble outlet in micron; and

18.3 is an offset pressure due to the level of ink in the chamber.

Substituting the first term into the Laplace equation, the surface tension  $\gamma$  of the ink was calculated as 33.5 mN/m. Independent surface tension measurements of the ink correlated well with this calculated figure.

Ink Cartridge Comprising Pressure Regulator

As shown in FIG. 4, the pressure regulator 200 comprises an ink chamber 201, which defines an ink reservoir for the printhead. Due to the simplicity and low-cost manufacture of the pressure regulator 200, it may be constructed as a replaceable ink cartridge for an inkjet printer. Hence, each time the ink cartridge is replaced, the pressure regulator is replaced. An advantage of this design is that long-term fouling of the

pressure regulator **200** is avoided, because it is periodically replaced during the lifetime of the printer.

#### Replaceable Ink Cartridge Connected to Pressure Regulator

In an alternative embodiment, the pressure regulator may be a permanent component of a printer. In this alternative embodiment, the pressure regulator is configured for connection to a replaceable ink cartridge. Hence, in the embodiment shown in FIG. **9**, the pressure regulator **200** is connected to a replaceable ink cartridge **280** via a pair of connectors. An ink connector **281** connects an ink supply port **282** of the ink cartridge **280** with an ink inlet port **283** of the ink chamber **201**. The ink supply port **282** and corresponding ink inlet port **283** are positioned towards a base of the ink cartridge **280** and ink chamber **201** respectively, to maximize usage of ink **104** stored in the cartridge.

A pressure-equalizing connector **285** is positioned to equalize pressure in the headspace **240** of the ink chamber **201** and a headspace **241** of the ink cartridge **280**. Corresponding pressure-equalizing ports **286** and **287** are positioned towards a roof of the ink chamber **201** and ink cartridge **280**, respectively.

When the ink cartridge **280** is empty, it is disconnected from the ink connector **281** and the pressure-equalizing connector **285**, and removed from the printer. A new ink cartridge can then be installed in the printer by the reverse process. Although only shown schematically in FIG. **9**, it will be readily appreciated that the ink cartridge **280** may have suitable connection ports **282** and **287**, which are configured for sealing engagement with the ink connector **281** and pressure-equalizing connector **285**, respectively, when the ink cartridge is installed in the printer. Connection ports suitable for such sealing engagement are well known in the art.

As shown in FIG. **9** the ink inlet port **283** and pressure-equalizing port **286** are defined in a sidewall of the ink chamber **201** which is opposite to the air intake plate **210**. However, the ports **283** and **286**, may of course be defined in the air intake plate **210** so as to simplify construction of the pressure regulator **200**.

#### Bubble Outlet Positioned in Headspace with Capillary Supply of Ink

In the pressure regulator described in FIG. **4**, the bubble outlet **207** is positioned so as to bubble air bubbles **209** into a body of ink **104** contained in the ink chamber **201**. Typically, the bubble outlet **207** is positioned towards a base of the chamber **201** in order to maximize ink usage at optimal hydrostatic pressure, with the air inlet **203** being positioned towards a roof of the chamber. A problem with this arrangement is that ink **104** contained in the chamber **201** can easily escape up the air channel **208** and out of the air inlet **203** during idle periods as a consequence of temperature fluctuations, whereby heating air in the headspace **240** increase the headspace pressure and forces ink up the air channel **208** and out of the air inlet **203**. Such temperature fluctuations are unavoidable and can result in significant ink wastage.

As already alluded to above, one means of addressing this problem is by incorporating a pressure-release valve **219** into the ink chamber **201**. This valve **219** is configured to release any positive pressure in the headspace **240**. However, valves of this type add significantly to the cost and complexity of the pressure regulator. Hence, the pressure-release valve **219** makes the pressure regulator **200** less amenable for incorporation into a disposable ink cartridge.

It would therefore be desirable to provide an ink pressure regulator, which does waste quantities of ink during temperature fluctuations and does not require a pressure-release valve, and which is therefore more amenable for incorporation into a disposable ink cartridge.

FIG. **10** shows an ink pressure regulator **300**, which meets the above-mentioned criteria. The ink pressure regulator is similar in design to that shown in FIG. **4** and still relies on controlling the Laplace pressure of air bubbles entering the ink chamber. However, rather than air bubbles bubbling into a body of ink contained in the chamber, the air bubbles enter the chamber via the headspace above the body of the ink. This design enables any excess pressure in the headspace to vent through the air inlet during idle periods, as will be explained in more detail below.

Referring to FIG. **10**, the ink pressure regulator **300** comprises an ink chamber **301** having an ink outlet **302**. One sidewall of the ink chamber **301** is defined by a laminated air intake plate **310** comprising first and second planar layers **311** and **312**, which cooperate to define an air inlet **303**, a bubble outlet **307**, a bubble vent **305**, an air (or regulator) channel **308**, a capillary channel **315** and a capillary inlet **316**. The bubble outlet **307** and bubble vent **305** are positioned above the level of ink in the chamber **301** so that air bubbles **309** enter the headspace **340** of the chamber via the bubble vent. The bubble outlet **307** is connected to the air inlet **303** via the air channel **308**. The bubble outlet **307** is generally slot-shaped and is critically dimensioned to control the Laplace pressure of air bubbles **309** as ink is drawn from the ink outlet **302**.

However, in contrast to previous embodiments, the air bubbles **309** are formed by air breaking through a meniscus of ink pinned across the bubble outlet **307** and adjacent bubble vent **305**, as shown more clearly in FIG. **11**. The so-formed air bubbles **309** emerging from the bubble outlet **307** escape through the bubble vent **305** and into the headspace **340** of the ink chamber **301**. Since the air must break through an ink meniscus, the air bubbles **309** are defined by an air cavity trapped inside a film of ink, rather than a whole body of ink. Regardless, the same Laplacian pressure control is still achievable, as described above.

The capillary inlet **316** provides fluid communication between the body of ink **104** in the chamber **301** and the capillary channel **315** defined between the two layers **311** and **312**. The capillary channel **315** is configured to provide sufficient capillary pressure such that a column of ink **304** rises up the channel at least as high as the bubble outlet **307**, thereby ensuring formation of air bubbles **309** by air breaking through a meniscus of ink. The capillary pressure is sufficiently high to re-form a meniscus across the bubble outlet **307** and bubble vent **305** after each air bubble **309** has vented into the headspace **340**.

The bubble vent **305** is dimensioned such that the column of ink **304** has a meniscus pinned across the vent by surface tension, as shown in FIGS. **11** and **12**. However, the bubble vent **305** should not be so small that it is susceptible to blockage by particulates. A bubble vent **305** having a diameter of the order of about 1 mm has been found to be suitable.

In practice, during idle periods when there is no significant pressure in the headspace **340** of the ink chamber **301**, the column of ink **304** rises above the bubble outlet **307** and typically pins across the entrance to the air channel **308**, as shown in FIG. **12**.

A significant advantage of the present embodiment is demonstrated in FIG. **13**. FIG. **13** shows the situation where a positive pressure is built up in the headspace **340** during an idle period. The pressurized air forces any ink from the air channel **308** and the air escapes from the chamber **301** via the air inlet **303**. Accordingly, only minute quantities of ink escape from the chamber **301** when the headspace **340** becomes pressurized due to temperature rises.

A further advantage of the present embodiment is that the air channel 308 is relatively short, thereby minimizing any flow resistance in the air channel and allowing high flow rates of ink from the chamber 301 with optimal pressure control. Any flow resistance problems (such as those described above

in connection with the embodiment shown in FIG. 4) are therefore avoided.

Bubble Outlet Positioned in Headspace and Isolated from Body of Ink

In the embodiment described above in connection with FIGS. 10 to 14, the bubble outlet 307 and bubble vent 308 are positioned in the headspace 340 of the pressure regulator 300. As shown in FIG. 13, this arrangement helps to minimize ink leakages via the air inlet 303 due to pressure fluctuations of the headspace.

However, even with the pressure regulator 300 configured in this way, there is still a mechanism by which ink 104 in the chamber 301 can escape. Since the capillary channel 315 provides fluidic communication between the air inlet 303 and the body of ink 104, then it is possible for ink to be pumped up the capillary channel by positive headspace pressure. If ink is pumped up the capillary channel 315, this negates the venting mechanism shown in FIG. 13 and significant ink losses may still result. It would be therefore be desirable to provide an ink pressure regulator, whereby ink losses due to temperature/pressure fluctuations in the headspace are further minimized.

FIGS. 15 to 19 show an ink pressure regulator 400, which addresses the problem of ink losses via the air inlet. The pressure regulator comprises an ink chamber 401, which contains a reservoir of ink 104, and an ink outlet 402 for supplying ink to a printhead. Pressure regulation is achieved similarly to the embodiment described above. Hence, air bubbles having a predetermined Laplace pressure exit from a bubble outlet and vent into a headspace 440 by breaking through a meniscus of ink. However, unlike the embodiment shown in FIG. 10, the bubble outlet and air inlet are fluidically isolated from the body of ink 104 contained in the chamber 401. This ensures minimal ink losses when the pressure regulator 400 is used in a printer. Prior to installation in a printer (e.g. during transit), all inlet and outlet ports in the chamber 401 may be plugged to prevent ink leakages.

Referring to FIG. 15, a sidewall of the ink chamber 401 is defined by a laminated air intake plate 410 comprising first and second planar layers 411 and 412. These planar layers cooperate to define first and second wetting chambers 450 and 460, interconnected by a regulator channel 415. The regulator channel 415 defines a bubble outlet 407 at one end and is therefore critically dimensioned to control the Laplace pressure of air bubbles exiting the bubble outlet.

The first wetting chamber 450 is open to atmosphere via an air inlet 403, whilst the second wetting chamber 460 opens into the headspace 440 of the ink chamber 401 via a vent 405.

The first and second wetting chambers 450 and 460 together retain a constant volume of liquid (typically ink) and function to ensure that the regulator channel 415 remains wetted at all times. (This function was performed by the capillary channel 315 in the embodiment described above). It is, of course, crucial that the regulator channel 415 and bubble outlet 407 are never dry when the regulator is required for printing operations, otherwise air can simply stream into the headspace 440 and pressure regulation fails.

Ink is transferable between the first and second wetting chambers 450 and 460 via the regulator channel 415. Hence, a volume of ink retained in each of the first and second wetting chambers 450 and 460 may vary depending on whether the bubble regulator 400 is supplying ink to a connected printhead during printing, or whether the bubble regulator is idle.

Referring now to FIG. 16, there is shown a magnified view of the regulator channel 415, first wetting chamber 450 and second wetting chamber 460 during an idle period. Each wetting chamber has tapered walls 451 and 461. In the first wetting chamber 450, the walls 451 taper towards the air inlet 403; in the second wetting chamber 460, the walls 461 taper towards the vent 405. This tapering (or chamfering) ensures that ink is retained in each chamber. The ink is pinned into edge regions of each chamber by surface tension, forming an annulus of ink at a perimeter of each chamber. A first annulus of ink 452 retained in the first wetting chamber 450 fluidically communicates with a second annulus of ink 462 retained in the second wetting chamber 460 via the regulator channel 415. Accordingly, as the volume of the first annulus 452 decreases, the volume of the second annulus 462 will correspondingly increase, and vice versa. This transfer of ink between the first and second wetting chambers 450 and 460 enables the pressure regulator to achieve a pressure regulation, whilst minimizing ink leakage as will be explained in more detail below.

Referring to FIG. 17, there is shown a magnified view of the regulator channel 415 and wetting chambers during printing. A pumping action of a printhead (not shown) connected to the ink outlet 402 draws air into the air inlet 403. The air pushes ink from the first wetting chamber 450 down the regulator channel 415 and into the second wetting chamber 460. Hence, the volume of the second annulus 462 increases relative to the first annulus 452. At the bubble outlet 407, which is the junction of the regulator channel 415 and the second wetting chamber 350, an air bubble 409 is formed and entrains into the second annulus 462 of ink. This bubble escapes from the second annulus 462 and into the headspace 440 by breaking through a meniscus 463 of the second annulus. The curvature of the air bubble 409 is determined by the dimensions of the regulator channel 415 and, hence, pressure regulation is achieved by the same mechanism described above.

Referring to FIG. 18, there is shown the situation where the headspace 440 is positively pressurized due to an increase in temperature. In this scenario, air from the headspace 440 pushes ink from the second wetting chamber 460, up the regulator channel 415 and into the first wetting chamber 450. The volume of the first annulus 452 of ink retained by the first wetting chamber 450 increases as a result. However, the first wetting chamber 450 is sufficiently large to accommodate this increased volume of ink, so that ink cannot escape through the air inlet 403. Moreover, the pressurized air from the headspace 440 vents from the air inlet 403 by bubbling through the first annulus 452 of ink. In this way, minimal or no ink losses result from day/night or other temperature fluctuations.

Evaporation represents one mechanism by which liquid retained by the first and second wetting chambers may be lost. However, since the headspace 440 is in equilibrium with both the body of ink 104 and the ink retained in the wetting chambers, any water lost through evaporation is recovered relatively quickly by water vapour in the headspace. The headspace 440 will always have a humidity approaching 100% provided that the ink chamber 401 is not empty.

The first and second wetting chambers 450 and 460 may have any suitable configuration, provided that they are able to retain a volume of liquid using surface tension. Referring to FIG. 19, it can be seen that, in plan view, the first wetting chamber 450 is generally circular (i.e. substantially frustoconical) and the second wetting chamber 460 is generally rectangular (i.e. substantially frustopyramidal). A substan-

tially frustopyramidal second wetting chamber **460** has been found, experimentally, to be particularly advantageous in avoiding ink losses.

The ink pressure regulator **400** as described above may define an ink cartridge for an inkjet printhead. Alternatively, a pressure regulating device comprising the first wetting chamber **450**, the regulator channel **415** and the second wetting chamber **460** may be manufactured separately and fitted to an ink cartridge, as appropriate.

It will be recognized that an advantageous feature of the ink pressure regulator **400** is that the pressure regulating components are isolated fluidically from the reservoir of ink contained in an ink cartridge.

#### Ink Supply System

It will be readily appreciated that the pressure regulators described herein may be incorporated into an ink supply system for an inkjet printer. The Applicant has developed previously a circulatory ink supply system comprising a pair of peristaltic pumps. The pumps are configurable for priming, depriming and printhead purging operations. This ink supply system is described in U.S. application Ser. No. 11/415,819, the contents of which is herein incorporated by reference.

FIG. **20** shows schematically a circulatory ink supply system incorporating an ink pressure regulator according to the present invention. As shown in FIG. **20**, the ink pressure regulator **300** is connected to a replaceable ink cartridge **280** via an ink connector **281** and a pressure-equalizing connector **285**. However, it will of course be appreciated that the ink pressure regulator **300** or **400** may be incorporated into a replaceable ink cartridge, as already described above.

The ink supply system comprises a printhead **105** connected to an upstream pump **150** and a downstream pump **151**. The ink cartridge **280** and ink pressure regulator **300** complete the circuit.

During normal printing, the upstream pump **150** is left open and the ink pressure regulator **300** controls the hydrostatic ink pressure in the system.

During storage, both pumps **150** and **151** are shut off to isolate the printhead **105**. Priming of the printhead **105** can be achieved by pumping ink to the printhead using the upstream pump **150**. Similarly, depriming of the printhead **105** can be achieved by pumping ink from the printhead back to the ink cartridge **280** using downstream pump **151**. The ink cartridge **280** typically comprises a filter for filtering any ink returned to it by the downstream pump **151**.

The printhead **105** may also be purged with air supplied from air inlet **152** by opening check valve **153** and pumping the downstream pump **151** in a reverse direction. The air

purge generates a froth or foam of ink at the printhead face, which is used for maintenance operations, as described in our copending U.S. application Ser. Nos. 11/495,815, 11/495,816 and 11/495,817, the contents of which are herein incorporated by reference.

It will, of course, be appreciated that the present invention has been described purely by way of example and that modifications of detail may be made within the scope of the invention, which is defined by the accompanying claims.

The invention claimed is:

**1.** An ink cartridge for an inkjet printer, wherein a laminated wall of said cartridge defines:

an air inlet;

a regulator channel having a first end communicating with the air inlet and a second end defining a bubble outlet, said bubble outlet being positioned for bubbling air bubbles into a headspace of the cartridge at all operative ink levels; and

a wetting system for maintaining at least some liquid in said regulator channel at all operative ink levels, thereby ensuring that air entering the headspace first passes through said liquid,

wherein said regulator channel is dimensioned to control a Laplace pressure of air bubbles drawn from said bubble outlet as result of supplying ink to a printhead, thereby regulating a hydrostatic pressure of the ink.

**2.** The ink cartridge of claim **1**, wherein said wetting system is fluidically isolated from an ink contained in said ink chamber.

**3.** The ink cartridge of claim **1**, wherein said wetting system comprises a wetting chamber in fluid communication with said regulator channel.

**4.** The ink cartridge of claim **3**, wherein said wetting system comprises a first wetting chamber communicating with said first end and a second wetting chamber communicating with said second end.

**5.** The ink cartridge of claim **4**, wherein said first wetting chamber is open to atmosphere via said air inlet.

**6.** The ink cartridge of claim **4**, wherein said second wetting chamber has a vent opening into said headspace.

**7.** The ink cartridge of claim **4**, wherein said liquid is transferable between said wetting chambers via said regulator channel.

**8.** The ink cartridge of claim **1**, wherein said liquid is ink.

**9.** The ink cartridge of claim **1**, wherein said wall is a sidewall of said cartridge.

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